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BIOMEDICAL AND BEHAVIORAL SCIENCES

(FOUO 4/81)

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HUMAN FACTORS

ENGINEERING PSYCHOLOGICAL DESIGN OF SEMIAUTOMATIC SYSTEMS THAT MAKE USE OF THE TRACKING PRINCIPLE

Moscow PSIKHOLOGICHESKIY ZHURNAL in Russian No 5, 1980 pp 105-116

[Article by A. P. Chernyshev, submitted 30 Nov 79]

[Text] The growth of semiautomatic systems in the world in the last few years indicates that such systems have become predominant at the present stage of technological progress [6]. In our opinion, the causes are as follows: in the first place, the limited technical capabilities for creating systems with complete automation of control processes and, in the second place, the drastic increase in their cost and complexity with increase in level of automation.

All semiautomatic devices are referable to the man-machine system class, and for this reason engineering psychological studies of interaction between them and man are gaining decisive importance to their design and operation.

Substantial changes have taken place in the requirements referable to man's mental activity in connection with scientific and technological progress; situations have begun to arise more and more often where the human operator is at the limit of his capabilities. In such cases, the human factor limits the function of the entire system.

Yet, there is still a rift between the approaches to describing the psychophysiological characteristics of man and machine parameters, due to the specifics of research methods in psychology and engineering. However, to develop an integral ["single"] man-machine system there must be an integral approach to it as a whole and a single language to describe it. Nevertheless, only one subsystem has been submitted to estimation and design thus far, the object of control, and the reason for this is the lack of well-substantiated principles of modeling the performance of an operator.

In order to take into consideration the human (primarily psychological) factor, it is particularly important to develop approaches to describing human performance that would permit ready retrieval of information to solve technical problems and, at the same time, to see the psychological meaning of manifestations of operator performance by means of criteria used in engineering practice.

At present, a general conception of engineering psychology has been formed as a science of information-related interaction between man and machines, as well as psychological regulation of controlling actions. The problem of designing the work of an operator has taken a central place in this conception.

This problem was formulated for the first time by B. F. Lomov, in 1963, and in 1967 it was formulated as one of the most important and promising problems of engineering psychology [5]. The past years have shown that this problem is becoming more and more pressing. The works of V. F. Venda, B. A. Dushkov, N. D. Zavalova, G. M. Zarakovskiy, V. P. Zinchenko, A. A. Krylov, V. I. Nikolayev, V. A. Ponomarenko, V. F. Rubakhin, A. V. Filippov and V. D. Shadrikov have dealt with various aspects of this problem. The work of K. K. Platonov, V. V. Chebysheva and others in the field of psychological analysis of work performance are very important to it. Academicians A. I. Berg, B. N. Petrov and V. A. Trapeznikov [1, 7, 12] have indicated the importance of work in this direction.

However, while there have been considerable advances in working on the bases of engineering psychological design of systems and performance, we must note that there has been extremely little work on development of specific methods for designing man-machine systems, in the development of which several problems arise. We shall list here the most important ones.

1. The problem of creating a common approach to the description of operation of the technical part of the system and operator performance.

2. The problem of consideration of individual psychophysiological characteristics of performance (these differences are of a random nature in a selected group of people).

3. The problem of consideration of dynamics of performance characteristics in the training process.

4. The problem of screening operators with the necessary characteristics for working with a specific control object (problems of training and occupational screening emerge as phases of the systems approach to the design of human work).

In our opinion, any technical part of the system, no matter how complex it is, is viewed as a tool of labor. On the one hand, the innate limitations of human capabilities require that work tools be created that broaden these capabilities; on the other hand, the work tools developed impose certain demands on human performance.

As we know, efforts to describe the operation of the machine part of a system and performance of an operator were made in engineering psychology in analyzing operator performance in the tracking mode. Use was made of mathematical models taken from automatic regulation theory (chiefly transfer functions). The first transfer functions describing operator performance in the tracking mode appeared in the United States in the 1950's (the models of McRuer, Krendel, Elkind and others [15, 16]). Subsequently, the system of nonlinear theory of automatic control (the model of Diamantides [17]) was used to create performance models; nonstationary and time variable models of operator performance were created [14, 18]. Such models were also developed in our country (A. V. Drozdov, I. Ye. Tsibulevskiy and others [9, 10]).

In the vast majority of cases, the developers of these models proceeded from the premise that the human operator is the functional element of a technical system, and the methods developed for analysis of such systems were used to describe his performance. The main description task was to define the "output" reactions of man to certain "input" signals.

The process of constructing mathematical models of performance is done mainly by two methods.

The standard model method consists of having the model, which is formed as an analog circuit [scheme], connected in parallel in the operating circuit with the operator. Man's action is compared to the model's output signal with regard to some criterion chosen in advance (most often the criterion of mean-square error). The parameters of the model are so adjusted as to minimize the selected criterion of comparison. This method makes it possible to identify the actions of the operator, but does not disclose the psychological characteristics of the actions proper. Such models can be useful and applicable only when the man in the system must be replaced by an automaton.

The method of spectral analysis permits description of the composition of response actions of the operator. The appearance of the link that performs such a conversion is determined from the appearance of the spectral composition of output and input signals as an approximation. The models created by this method are referable to the quasilinear class. They too do not permit the study of psychological distinctions of human actions (their structure and mechanisms of psychological regulation).

Whatever the means used to develop them, most mathematical models did not find practical applications. And this is not because the very idea of developing mathematical models of performance is not fruitful. On the contrary, as observed by B. F. Lomov, modeling is "a powerful means of constructing psychological theory" [4]. A. A. Krylov, V. N. Nikolayev, V. F. Rubakhin, V. D. Shadrikov and others also rate highly the role of modeling in analysis of operator performance and its formalization. The fact of the matter is that the above-mentioned mathematical models did not adequately describe the psychological distinctions of operator performance.

First of all, they did not reflect important features thereof, such as dependence of reaction on form and significance of input signal, adaptive capabilities of the operator, his fatigability; dependence of the reaction on conditions of performance, level of operator motivation, his functional state, etc. They overlooked the fact that operator actions are mediated by mental reflection, by the conceptual models, operational images of the control object. As a result, the operator could not be distinguished from the machine, and his specific traits were overlooked. The basic principle of Soviet engineering psychology, which states that the relationship between man and machine in control systems is the relationship between the "subject of labor and tool of labor" [4], is not applied in the construction of these models. For this reason, only the external, resultant manifestation of distinctions of the work under study was reflected in the models in question.

Most systems, with the exception of the simplest ones, can be described only approximately by mathematical equations. This is attributable to the fact that we either do not know all of the factors that affect their behavior, or that we obtain excessively cumbersome equations that are difficult to solve by modern methods. Applied problems usually deal with a small number of aspects of system behavior. For this reason, the mathematical model has to be made as simple as possible, in order to concentrate on the study of the parameters that have the strongest influence on the behavior of the system. Consequently, as the first step in our study, we must become convinced of the fact that the mathematical model is adequate for the system modeled.

When working with a simplified model, one must be cautious and constantly check whether the assumptions made are still valid when changing to the study of a new system. It is desirable for the model to be general enough, so that a wide range of processes and variations of the work under study can be simulated.

Mathematical models help us comprehend the behavior of complex systems, and to predict it; they are useful in training. They can be used to analyze various control situations, to demonstrate or formulate new problems, develop new principles for the design of technical systems and algorithms of operator performance.

As we have already stated, the use of transfer function is one of the popular methods of modeling human performance. Indeed, this function is the most convenient form of describing the dynamics of system function in the practice of designing automatic control systems. This rather simple idea drew the attention of many researchers concerned with modeling operator performance [3, 9, 10, 14], although the term "human transfer function" is not used quite correctly in the psychological literature. It seems obvious that there will be different correlations for open and closed systems including an operator. Man performs a different conversion of input information in an open and closed system, while the usual element of the automatic control system does not change its properties, whatever circuit it is connected to. Moreover, having identified the mathematical model of operator performance in one situation, it is virtually never possible to extrapolate it to another situation. For this reason, the question arises as to the validity of using the concept of transfer function to describe the performance of a human operator.

What is a transfer function? To what class of systems does this concept apply? Can one extrapolate this function to the description of man's performance in the system? If so, what is the range of application of this concept?

In automatic control theory, the concept of transfer function was initially introduced for the class of linear systems, i.e., systems to which the superposition principle applies. It consists of the following: if several perturbing factors are applied to a linear system simultaneously, their joint effect equals the sum of effects induced by each factor separately.

The principle of superposition enables us to describe the reaction of a linear system to an arbitrary perturbation in the form of the sum of reactions of this system to elementary perturbations, for which purpose it is sufficient to make an expansion. Then, knowing the reaction of a linear system to elementary perturbations of this type, we can define its reaction to arbitrary perturbation by applying the superposition principle. As a result, the dynamic properties of the linear system are entirely characterized by its reaction any standard type of perturbation. In principle, one can always choose any type of elementary perturbation and, according to it, define the characteristics of a linear system.

In so doing, one must be governed by the following considerations: the class of the function, which can be expanded according to type of elementary perturbation of the type we selected, must be as broad as possible; such expansion should not present any difficulties.

We obtain various characteristics of the linear system, depending on the choice of type of perturbation. But each of these characteristics will be exhaustive, since knowledge thereof is sufficient to find the reaction of the linear system to any perturbation. There can be the following types of elementary perturbation: harmonics, delta [Dirac] function, or step function. Accordingly, a distinction is made of the following: frequency characteristics in the case of harmonic perturbation; pulsed transient function with perturbation in the form of a Dirac function; transient characteristics in the case of stepwise perturbation fed to the system's input. They are all interrelated and can be derived from one another. If one of these characteristics of the system is known, one can define the output signal with arbitrary perturbation. Thus, the frequency, pulse and transient functions of the system, or any other characteristic, completely define the properties of a linear dynamic system. They depend only on the system's own dynamic properties, and they are unrelated to the parameters of factors influencing it. The frequency characteristics of the system $\Phi(j\omega)$ are related to the pulsed transient function $k(t)$ as follows:

$$\Phi(j\omega) = \int_0^{\infty} k(t)\, e^{-j\omega t} dt.$$

The pulsed transient function of the system is related to the frequency characteristic by inverse Fourier transform:

$$k(t) = \frac{1}{2\pi} \int_{c-j\infty}^{c+j\infty} \Phi(j\omega)\, e^{j\omega t} d\omega.$$

The transient characteristic $h(t)$ and pulsed $k(t)$ are related as follows:

$$k(t) = \frac{dh(t)}{dt}.$$

Transfer function $\Phi(s)$ of the linear system is expressed through a pulsed transient function by means of direct Laplace transform:

$$\Phi(S) = \int_0^{\infty} k(t) \cdot e^{-st} dt.$$

The transfer function is defined as the ratio of the system's output, transformed according to Laplace, to the system's input transformed according to Laplace at zero initial conditions.

This definition is often used in the psychological literature without consideration of the system's class, which leads to erroneous interpretation of the concept of transfer function. For example, in [8] there are 20 mathematical models of operator performance only in the tracking mode, which were obtained by different authors between 1951 and 1968. Since the transfer function of a linear system is unrelated to the type of input factor (it is determined solely by the properties of the system itself), the profusion of mathematical models, even for the same type of performance, obtained by different authors indicates that the principle of superposition for this class of systems has not been adhered to. This means that the concept of "operator transfer function" is invalid, even for the same type of work.

In spite of the fact that the concept of transfer function is valid only for linear systems, efforts were made to apply it to analysis of nonlinear systems [2]. The analog of transfer function for nonlinear systems is known under the name of image [representative] function. This concept is based on the fact that the response of a nonlinear system to harmonic perturbation is occasionally very similar to the harmonic signal (thus, if we take into consideration only the first harmonic of the output signal and disregard the presence of higher harmonics, we can find at each frequency the ratio of amplitudes of the system's output to its input. In the general case, this ratio depends on the amplitude and frequency of the input signal, and in a linear system only on frequency). The procedure of substitution of a nonlinear system with a linear one is called linearization of a system, i.e., the actual performance of the operator is described by a linear model that offers the best approximation to real performance.

Let us consider the possibility of constructing an image function of operator performance, limiting ourselves to modeling simple sensorimotor activity, without dealing with more complicated cases. Compensatory tracking in one plane of a harmonic signal may be a form of such activity.

The proposed experiment consisted essentially of the following. A low-frequency generator of periodic oscillations was used to deliver a harmonic signal; the operator tracked it by means of a potentiometer control handle. The tracking error that was formed in this process was fed to a display (cathode-ray oscilloscope with screen 15 cm in diameter and 8 cm range of beam oscillations). The distance between the display screen and the subject's eyes was 70 cm. The experiment was conducted in daylight. The control had a 1-m lever (distance from point of application of controlling action to axis of potentiometer sensor). An amplification unit served as the object of control.

The operator can predict well the harmonic signal, and he adapts easily to changes in its characteristics. Thus, a harmonic signal is fed to the input of the man-machine system (Figure 1), and there must be the same harmonic signal at the output of this system, without phase lag and, consequently, in the ideal case, the transfer function of the man-machine system should equal one.

For a formalized description of performance, we must consider the exogenous effect on the operator and his reaction. Here, we can distinguish two phases. The first phase is when the operator perceives a mistake in the system, which is delivered from the display to the visual analyzer in the form of a harmonic signal. There is no human reaction. This is the phase of perception of the harmonic signal. The second phase is when the motor reaction, even of an experienced operator does not conform with the delivered signal. The operator perceives the error on the display in the form of a stationary random function of time. This is the phase of stationary activity. The error is a stimulus that causes regulation of sensorimotor transformation. However, we cannot rule out the possibility that termination of the first phase does not mean that there is traceless disappearance of the sensory graphic image of the harmonic signal. It may be that further tracking occurs with involvement of representation mechanisms. To rule out or accept this hypothesis, the following experiment is conducted: the operator is asked to track a harmonic signal while the mean of tracking error disappears from the display screen at a time that is not known in advance to the operator. The operator continues with the tracking, reproducing the previously presented signal by representation (the frequency of which was fixed in each specific experiment). The experiment was continued in the range of 0.05 Hz to disruption of operator tracking.* Since tracking error is a variable, determination was made of statistical characteristics of error in tracking when the display beam is on. The boundary of the statistical "tube" of error was plotted. An error is a stationary random process with a polyharmonic component, and it is a stable feature for each operator. Then the segment of oscillogram obtained with the display beam off was submitted to statistical processing (Figure 2). The time during which the statistical operator error was in the range of the "statistical tube" depends on the frequency of presented harmonics and is little-related to individual distinctions of trained operators. Figure 3 illustrates such a function for two operators:

$$\tau_c(f) = \frac{t_{c_i}(f)}{\sigma_{e_i}(f)},$$

where $\tau_c(f)$ is the relative time of operator work in the "statistical tube" of error with display beam off; $t_{c_i}(f)$ is absolute time of operator work in the statistical range of error with display beam off; $\sigma_{e_i}(f)$ is mean-square deviation of error signal with display beam on; f is frequency of presented signal.**

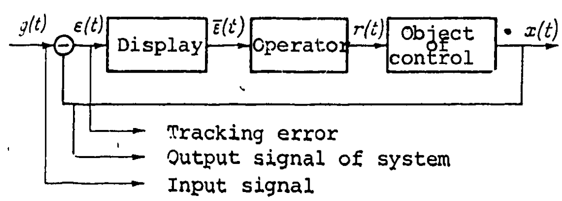


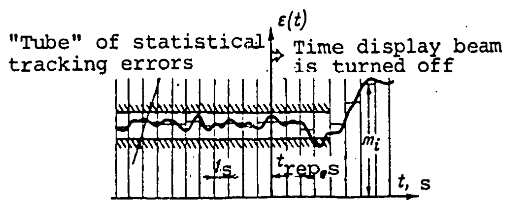
Figure 1. $g(t)$--input signal of system $\varepsilon(t)$--tracking error
$x(t)$--output signal of system $r(t)$--operator's control signal

As a result of processing, it was found that the maximum time that an operator can work within the statistical tube of error does not exceed 4 s at a frequency of 0.05 Hz and 2 s at 0.1 Hz. The time diminishes drastically with increase in

*Disruption of tracking refers to the magnitude of dispersion of error, which equals dispersion of input signal, i.e., the case that is tantamount to operator inaction.

**Subscripts "c" and "e" refer to "correct" and "error."

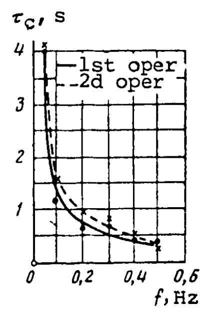
frequency of delivered signal. Consequently, the action of the mechanism of representations is limited to a maximum of 4 s. Evidently, the hypothesis of operator function in excess of 4 s according to representation [imagination?] should be set aside because it was not confirmed experimentally.



$\varepsilon(t)$--tracking error
t--current time, s
t_{rep}--time of operator work by representation
m_i--mathematical expectation of error signal in partition interval

Figure 2.

The experiments revealed that the error displayed to the operator on the oscilloscope screen, in spite of its seeming randomness, contains a harmonic component, in addition to random noise, which corresponds to the harmonic of the signal delivered to the input of the man-machine system. Although the main harmonics contained in the tracking error are much smaller in amplitude than the harmonics of the delivered signal, this information is quite sufficient for dominance of amplitude at the frequency of the input signal in the operator's reaction. The appearance of additional harmonics in the operator's response is indicative of the effect of nonlinear transformation of input signal by the operator. Nonlinearity of transformation can be evaluated as a function of coherence.



τ_c--reduced tracking time according to representation, s
f--frequency of delivered harmonic signal, Hz

Figure 3.

First of all, we shall demonstrate that the coherence function equals one with linear transformation of the signal:

$$\gamma = \frac{|S_{gx}(\omega)|^2}{S_{gg}(\omega)\, S_{xx}(\omega)} = 1.$$

The spectrum of the output signal in the case of linear transformation is expressed by the function:

$$S_{xx}(\omega) = |\Phi(j\omega)|^2 S_{gg}(\omega),$$

where $\Phi(j\omega)$ is the system's frequency characteristic.

The reciprocal spectrum $S_{gx}(\omega)$ can be readily found if we write down the output of linear transformation of the system in the form of Duhamel's integral:

$$X(t) = \int_0^\infty k(\tau) g(t-\tau) d\tau,$$

where $k(\tau)$ is the pulsed characteristic of the system in question. By multiplying the left and right parts of this equation by the signal $g(t)$, averaging and taking the Fourier transform, we shall obtain the reciprocal spectrum $S_{gx}(\omega)$ in the following form:

$$S_{gx}(\omega) = \Phi(j\omega) S_{gg}(\omega).$$

Substituting the found values in the equation for coherence function, we find that for a system that performs linear transformation the coherence function equals one.

In order to find the zone where ordinary linearization of performance is possible in the mode of compensatory tracking, we plotted the function of coherence between the error presented to an operator on the display and his motor reaction.

In our experiment, we found that the coherence function is close to one only when the frequency spectrum of the input signal does not contain frequencies above 0.5 Hz. The presence of higher frequencies lowers the coherence function and, consequently, the operator performs nonlinear transformation of the input signal. Thus, for input signals containing no frequencies above 0.5 Hz, the operator controlling the object of control described by an amplifying unit can be formally identified as an image function.

Figure 4 illustrates the spectra of operator error in the course of training in tracking. Figure 4 shows that new elements appear in the spectrum of operator actions with increase in number of exercises. A change in control situation, parameters of input signals, parameters or structure of the control object leads to a change in these components.

Analysis of the spectrum of reactions of a trained operator shows that, in addition to the required harmonics, it contains several other harmonic components and a random process, which are not provided by the objective of a given activity and are an error for the man-machine system. Such movements, which are an error from the standpoint of efficient operation of the system, are at the same time necessary to formation of an image of the controlled object, and they give the operator information about the status of the object of control. In order to obtain the necessary information to form adequate controlling actions, the operator must make additional motions that diminish the accuracy of operation of the man-machine system but permit performance of the tracking process.

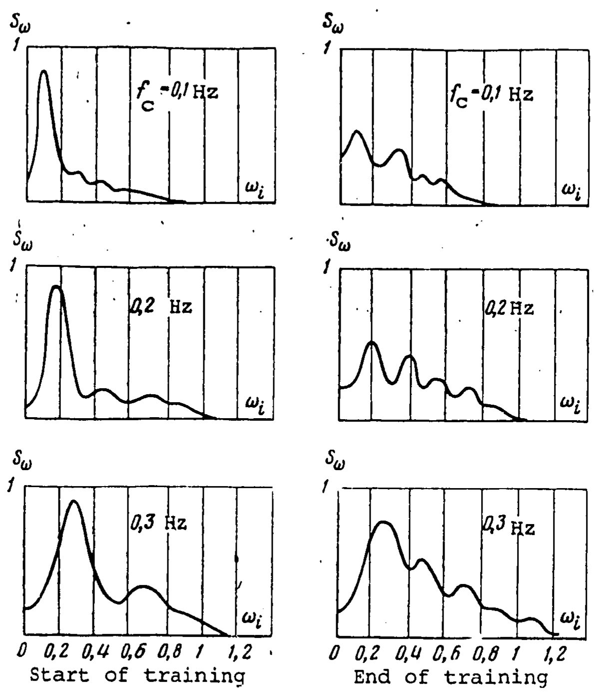


Figure 4. $S\omega$--standardized spectral density of delta remnant
ω_i--current frequency, Hz
f_c--frequency of delivered signal, Hz

This spectrum of additional movements in relation to ideal control is needed by the operator to "learn" and control the control process was named the delta remnant, but only in the case where the transfer function of the object of control equals one and the input signal is a harmonic. This definition is convenient in that a change in any factor affecting the quality of tracking, for example, parameters of the object of control, characteristics of exogenous factors, changes in psychophysiological state of the operator, etc., leads to appearance of new quantitative and qualitative changes in the spectrum of the tracking process, and these factors can be evaluated as characteristics of the spectrum of additional movements.

The informative nature of additional tracking movements was determined experimentally. Dynamic inertial and oscillatory elements were connected into the control circuit, and they constituted filters of specific frequencies. Their filtering properties are determined by the values of the parameters. Inclusion of these elements in the circuit, which simulate the properties of the object of control, rendered operator work substantially more difficult; there was a drastic increase in tracking error and disruption occurred sooner. It was found that if such a filter element "cut off" part of the spectrum of reactions that contained information for the operator there was a drastic deterioration of quality of performance. On the other hand, addition to the circuit of control of an element generating additional harmonics (nonlinearity) also increased the number of additional operator actions and thereby worsened tracking quality. Thus, according to our data, the operator uses information that he provokes himself in order to form controlling actions in tracking. A decrease in such information due to filtration or "enrichment" thereof due to generation of new harmonics worsens operator performance.

The results of experimental analysis of operator performance referable to compensatory tracking disclose the sort of dual nature of additional movements. On the one hand, they constitute a tracking error, i.e., they are a negative factor; on the other hand, a certain part of these movements, which is informative in nature and a manifestation of specific operator activity, is needed for successful tracking. It is important to recall that, from the standpoint of regulation theory, minor additional movements contained in the error do not play a role in the tracking process, since they are not controlling. For expressly this reason, they were not considered in creating mathematical models.

Determination of the informative nature of errors made it possible to consider the different aspects of operator performance of the tracking type from a different angle.

In the study of the process of acquiring tracking skill, determination was made of the coherence function, which characterizes the type of sensorimotor transformation of information delivered to the operator's visual analyzer. With increase in number of practice exercises the coherence function diminished, and it became constant by the end of the training period.

This shows that formation of tracking skill is related to formation of informational movements that distort the linearity of sensorimotor transformation. It was demonstrated that the more training an individual has had, the less linear his transformation of input signal into an output signal. This finding, which appears paradoxical at first glance, indicates that there is reorganization of processes of receiving and processing information by an operator in the course of training.

Thus, we consider minor additional movements as necessary elements of a mathematical model of a man-machine system, which are determined by the distinctions of mental regulation of human actions.

Development of a linear model requires that these movements be disregarded because of their smallness; however, if they are overlooked there is loss of information about psychological regulation of activity. Slight movements are one of the indicators of psychological distinctions of operator work in the tracking mode. The lack of formalized description of the properties of these movements in mathematical models of performance is the cause of their inadequacy. Inclusion thereof in mathematical models makes it possible to take into consideration the psychological distinctions of human performance. This proves the usefulness and applicability of the proposed method of analyzing small additional movements to gain deeper understanding of psychological distinctions of operator performance, and also offers new quantitative criteria for evaluating this performance.

Since any system is developed for a certain set of people, of course the characteristics of such movements are of a random nature from person to person, while the characteristics of a set of people that have to operate the system can be described by a certain law of distribution. The range of scatter in this set is set by the tactical and technical specifications, and it determines the accuracy of a man's work in this system.

The elements of the technical part of the system are always made with certain allowances due to the inevitable technological flaws in production, which are of a random nature. For this reason, the characteristics of the system as a whole are random, and any man-machine system is stochastic.

Analysis of accuracy of the most frequently encountered block diagrams (structural diagrams) describing a semiautomatic system, in the presence of scatter of parameters, makes it possible to solve the problem of defining requirements in common for the scatter of machine parameters and functional characteristics of an operator. By solving this problem, we can define the permissible scatter of parameters of the machine part of the system and permissible scatter of functional characteristics of man in accordance with the tactical and technical specifications made of the system being developed. The permissible scatter of characteristics of operator performance defines the ranges of parameters, in the presence of which the set of operators is suitable for working in a given system. Otherwise, the operator does not meet the requirements for a given performance in a system, which are imposed by the work tools on the functional characteristics of man.

At the present time, these specifications are usually formed after the system has already been developed. However, even at the design stages, it is imperative to take into consideration the functional characteristics of a human operator, and moreover of an entire set of operators, rather than a single one, as they will be operating the system in question. The early stage of system design is characterized by the fact that there is neither an object of control nor set of operators whose performance must be designed. The mechanocentric approach made it necessary to first design the object of control, then to screen operators for this object that have the required psychophysiological characteristics. The proposed systems approach means that the object and human performance are designed from the same vantage point and with the same specifications at the very earliest stages of development of man-machine systems.

As a result of studying slight movements, it became possible to assess analytically the share of error contributed to output signal error of the system attributable to both the performance of the operator and scatter of parameters of any element of the machine part of the system. This, in turn, made it possible to synthesize a system in accordance with specified tactical and technical requirements, i.e., to determine the permissible scatter of machine parameters and scatter of functional characteristics of operators according to known output characteristics of the system determined by tactical and technical specifications.

The capabilities of the method developed are to specify an allowance for scatter of parameters of any element of the system according to specified accuracy-related characteristics of the system's output signal and, in addition to industrial, technological considerations, they should also be based on economic considerations.

On the basis of analysis of statistical data on system production and data pertaining to the training of highly skilled operators, analytical functions were obtained of cost of production of system elements (and the entire system) as related to precision of production and expenses for operator training as a function of qualification requirements. These functions were named cost functions.

Cost functions define the restrictions imposed by economic considerations on the production of semiautomatic systems. The range of permissible parameters established as a result of system synthesis makes it possible to vary the parameters of the machine part of the system and functional characteristics of operators in accordance with the nature of changes in cost functions referable to production of its elements and operator training. Use of cost functions in the practice of design makes it possible to create economical systems.

Thus, consideration of design of performance using the systems approach makes it possible to analyze from the same [common] positions the exogenous manifestations of human performance and operation of the technical part of the system, as well as to study the mechanisms of formation of subjective reflection of the states of the object of control.

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COLLABORATION OF SOCIALIST NATIONS IN THE FIELD OF ENGINEERING PSYCHOLOGY

Moscow PSIKHOLOGICHESKIY ZHURNAL in Russian No 5, 1980 pp 146-152

[Article by V. F. Venda]

[Text] Specialists of social countries have deployed in recent years research in the field of engineering psychology and have made considerable strides in a number of new directions, in implementation of the decision of national congresses of communist and worker parties pertaining to development of automated control systems, improving the efficiency, quality and safety of labor.

Attention was concentrated mainly on refining methods of psychological analysis of the structure of work activity, evaluation of its intensity, development of theory and practical methods of improving the quality and efficiency of controlling machines, units, industrial, transportation, energy, aviation and space equipment, by optimizing interaction between man and machine. The recommendations to take into consideration the psychological distinctions of performance are used extensively in processes of designing, operating and rationalizing machines, systems and control equipment. At the present time, work on many promising systems is starting with preparation of an engineering psychological plan for operator performance, definition of principles and methods for operator screening and training.

It is becoming possible to solve such a complex problem as mutual adaptation of a human operator and control equipment thanks to the intensive development of the systems approach in psychological research. In this regard, the work of B. F. Lomov [1], V. P. Kuz'min [2], A. A. Krylov [3], D. Kovac [9], J. Daniel [10], F. Klix [12], W. Hacker [13], N. D. Naplatanov [14], Yu. P. Marinov [15] and other scientists from socialist countries played a fundamental part.

The systems approach made it possible to refine engineering psychological design and rationalization of modern control equipment, as well as to undertake development of forecasts of promising structures of man-machine systems.

At the same time, the practice of building of communism and socialism poses more and more complex problems to specialists in the field of engineering psychology. They can be solved, provided the efforts of specialists of socialist nations, CEMA members, are integrated.

One of the most pressing theoretical and practical directions is development of engineering psychological requirements for equipment that displays information to operators, including equipment for output of data from computers. This direction was approved as CEMA project 1-37.IV, work on which is being pursued in accordance with the 1976-1980 program for multilateral collaboration.* Specialists from the People's Republic of Bulgaria, GDR, Poland, Czechoslovakia and the Soviet Union are working on this project. The Institute of Psychology, USSR Academy of Sciences, was assigned to implement scientific coordination of work on this project.

The research program for project 1-37.IV specifies three tasks. The first is "Development of theoretical bases of engineering psychological design of equipment for displaying [reflecting] information."

This task involved development of a classification of types of information display equipment (IDE), which was completed by the Industrial and Scientific Research Laboratory of the Higher Mechanics and Energy Institute (Sofia, People's Republic of Bulgaria) headed by Yu. P. Marinov; the results of these studies have been published [15]. Within the context of the same assignment, the Institute of Psychology, USSR Academy of Sciences, is studying determination of processes of solving operational problems by the type and structure of IDE, as a result of which there was formulation of the structural psychological conception of analysis and synthesis of IDE [4], which was discussed at a scientific coordinating meeting dealing with project 1-37.IV in Moscow, in 1978, and which was approved as the main theoretical conception.

This conception is a special offspring of the systems approach to engineering psychological studies, which was developed by B. F. Lomov [1]; here, the structure of the information display system is related to the values of psychological factors of difficulty of solving operational problems.

On this bases, the objective of engineering psychological design is to aid in optimizing psychological factors of difficulty [complexity] (PFD). In the course of the scientific coordinating meeting, it was noted that this approach to engineering psychological design of IDE has some advantages over other conceptions in engineering psychological design. In particular, it takes into consideration the many variants of processes of solving operational [immediate, ongoing] problems, and it interprets overtly the principles of "assembly," "organization," "structuring" of information display systems as means of materialization in their structures of a priori solution strategies; it permits addition and analysis of a quantitative gage of determination of real strategies by a priori ones.

The systems approach makes it possible to view problems of engineering psychological design not only as preliminary adaptation of a machine to man, but on a much broader scale, as multistage, multilevel adaptation, both reciprocal and related: man to machine and machine to man. As a result, broader self-organization properties are imparted to the system.

Use of methods of analysis and organization of interaction between a priori and actual strategies is not limited solely to instances of engineering psychological design of operator performance. This approach is also used to solve other problems

*This project is part of the work dealing with CEMA problem No 1-37, "Development of scientific bases of ergonomic standards and requirements." A coordinating council for this problem was established at the All-Union Scientific Research Institute of Esthetics in Engineering, and this council is headed by V. M. Munipov, candidate of psychological sciences.

of design of man-machine and man-computer systems, for example, to determine the desirable level of automation of experimental scientific research. In the case where a priori strategy is taken as the basis of some paradigm of research and it must be executed many times to accumulate homogeneous experimental data, i.e., when the a priori strategy can be repeated without any creative intervention on the part of experimenters in the course of the experiments, there can be complete automation of research. But when the experimenter actively influences refinement of methods (i.e., a priori strategies) of research, as is usually the case in modern applied psychology, the experimental device must be designed on the basis of adaptive informational interaction between man and machine.

Organization of adaptive interaction of a priori and real strategies is the road toward more efficient use of the capabilities of modern information and computer technology, as well as definition of the prospects of its development to create more sophisticated man-machine systems.

In the future, the basis may be formed for synthesis of "hybrid intelligence" systems [16, 17] on the basis of the principles of organization of adaptive informational interaction between complexes of a priori and real strategies offered by information and computer technology and active participants in the solutions [decisions].

The Leningrad State University, All-Union Scientific Research Institute of Esthetics in Engineering (Leningrad branch), Leningrad Electrical Engineering Institute, Scientific Research Institute of Peripheral Equipment (Kiev) and the Central Scientific Research Institute of Complex Automation are working with the Institute of Psychology, USSR Academy of Sciences, on development of theoretical and methodological bases of engineering psychological design of IDE. The work of these organizations is related to the study and refinement of languages for dialogs between man and computers, studies of tension and fatigue of individuals working at a console with a screen (display), and development of methods for engineering psychological design of automated control systems.

The intensive work being done on methodological bases of engineering psychological analysis and design of man-machine systems, with the participation of many scientists and specialists, made it possible to create an hierarchy of approaches and methods that permit analysis of such systems on different levels to varying degrees of detail.

The highest level involves the structural systems approach [1]. This is followed by analysis of psychological factors of difficulty of reaching goals, problem solving by man. Such analysis is based on the structural psychological conception [4]. If the problem-solving process and performance of functions by man can be presented in the form of a stable block diagram, analysis of efficiency and reliability of the system is made on the basis of the generalized structural method developed by A. I. Gubinskiy [5].

When it is possible to provide not only a block description, but one of each operation, one after the other, in the processes of operator work, one uses algorithm methods, which have been studied comprehensively in application to man-machine systems by G. M. Zarakovskiy and A. I. Galaktionov [6]. In the general case, block and operation analysis of performance are used to define certain PFD, such as the number of operations in the algorithm of decision making and its implementation.

The use of simulation models is successful to some degree when the operations performed by humans, both individually and as a group, in the course of joint control of the system are known.

When analyzing the dynamics of deterministic man-machine systems, a systematic refinement of description thereof is achieved by turning to discrete, pulsed and, finally, analogous (continuous) mathematical models. This level corresponds to the most comprehensive and strict description of work processes, which is applicable to a relatively limited range of well-known functions of an operator, such as compensatory tracking, for example [6]. Studies must be made on each level of analysis of the possibility of optimizing the system on the basis of reciprocal adaptation of man and machine.

The results of studies dealing with the theoretical aspects of engineering psychological design of IDE are summarized in the following books: "Engineering Psychology. Theory, Methodology and Practical Applications" ("Nauka," Moscow, 1977) and "Psychological Problems of Mutual Adaptation of Man and Machine in Control Systems." The second book is ready for publication by "Nauka" Publishing House, and its authors include scientists from the People's Republic of Bulgaria, GDR, USSR and CSSR (the editors in chief are B. F. Lomov, V. F. Venda and Yu. M. Zabrodin).

The second assignment in project 1-37.IV is "Engineering Psychological and Ergonomic Studies of Information Receiving and Processing as Related to Different Features of IDE." These studies are coordinated by the Institute of Labor Safety (Prague, CSSR), and the following are participants: Institute of Experimental Psychology (Bratislava, CSSR), Institute of Engineering Cybernetics, Bulgarian Academy of Sciences (Sofia), Center for Esthetics in Industry and Artistic Design (Sofia), Leningrad State University (USSR) and Institute of Esthetics in Engineering (Warsaw, Polish People's Republic).

Research on preparation of information for decision making when working with various code symbols, studies of the principles of multidimensional coding of visual and auditory information are being pursued at Leningrad State University, under the guidance of Prof A. A. Krylov; together with this university, the Institute of Psychology, USSR Academy of Sciences is studying information receiving and processing in the case of simultaneous delivery thereof via visual and auditory channels. K. Lapachevska and D. Senk, at the Institute of Esthetics in Engineering (Warsaw) are studying the structure of the visual field as related to intensity of flow of information.

Extensive studies are being pursued by J. Daniel and his coworkers at the Institute of Experimental Psychology (Bratislava, CSSR) in the area of information receiving and processing as related to change in intensity of delivery thereof to IDE; special emphasis is laid in this work on studies of the influence of information load on cognitive processes when introducing automated control systems and computers.

At the first stage of this research, J. Daniel concentrated mainly on determination of the main parameters of physical and mental tension and study of perceptual processes in the presence of a load. Catecholamine levels were chosen as an indicator of the load. It was shown that individuals with good resistance to loads (both physical and mental) secrete more epinephrine in experiments. At the second stage, adaptive mechanisms associated with long-term exposure to loads were the main topic of studies. It was established that, after an anticipation phase characterized by intensive output of epinephrine, there is a decline of catecholamine level with further exposure to stressors, labor efficiency improves while the feeling of fatigue diminishes. A consistent link was demonstrated between the effect of an information load and such personality traits as level of anxiety, neuroticism, integration of personality and strength of nervous system (according to the tests of Ayzenko, Strelau and Mikshik questionnaires).

The interdisciplinary approach to analysis of work processes, which is being developed at the Institute of Experimental Psychology (Bratislava) under the guidance of D. Kovac, made it possible to combine previously different levels of structural-functional, psychological, psychophysiological and physiological analysis. Use of this systems methodology yielded a number of new findings and results in studies and rationalization of various industrial occupations. Special mention must be made of the significant contribution of M. Strizenec [11] to the complex psychological work on the problem of man's interaction with computers.

Extensive studies of cognitive processes that regulate work performance are being conducted by Prof W. Hacker at Dresden Polytechnical University (GDR). He uses a combination of methods: analysis of production process, observation of work processes on different levels of differentiation and field (natural) experiments. This author demonstrated that the separate, unrelated use of any of these procedures alone is ineffective.

Modern analysis of work processes is based on principles of quantitative analysis of psychological regulation and psychodiagnostic principles of demonstration of stable prerequisites (abilities) for a given type of work. W. Hacker demonstrated that psychological analysis of work processes must include consideration of their processual and structural elements in order to demonstrate and upgrade the control and effector elements of performance. There must also be analysis of goal formation, specifics of recognition and differentiation of states. Special attention must be given to diagnostics [identification], i.e., classification and evaluation of states, transformation of graphic and conceptual (logical) elements of regulation, including the decoding of information, recognition, mathematical and logical operations, conversion of reference systems, etc. The study of "managerial knowledge," system of immediate [operational] patterns, actualization thereof when searching for solutions, processes of formation of new work procedures, prediction of possible consequences, performance of monitoring and effector sensorimotor operations constitute an independent group of problems.

N. D. Naplatanov, Yu. P. Marinov, P. Khadzhiyev, K. Tropolov and other scientists of the People's Republic of Bulgaria are elaborating principles of IDE synthesis intended for the control of stationary and moving objects, on the basis of the methods of psychological and psychophysiological analysis of work activity, which are being developed by the scientists of CSSR and GDR, within the framework of the second assignment contained in project 1-37.IV.

N. D. Naplatanov et al. [14] demonstrated that man-machine systems have many circuits and many channels; they contain internal links that are extensive in nature and goals, elements of a rather high hierarchic level of organization and high-density flows of information circulating over the external circuits of the systems. For this reason, studies, design and construction of such systems should take place as a functional entity by means of methods used for the study of cybernetic systems, regardless of the fact that the main units are governed by their own specific principles and patterns in their function. These studies are based on the systems approach. It consists of complex, interrelated and proportionate consideration of all factors, ways and means of solving a complex, multifactorial and multivariant problem, a typical example of which are problems related to the study of man-machine control systems. To solve these problems, there must be close correlation of a wide range of scientific and practical data, as well as large material-technical and labor resources, flexible enough and suitable for the relevant level of adaptation of forms of organization. The systems approach considers control systems as an integral whole, with all its aspects, proportionately to their weight and significance.

Unlike classical engineering psychological design, with the use of the systems approach all factors of the system being designed are taken into consideration tional, psychological, social and esthetic), which leads to appearance of new phases in the designing process and, first of all, in engineering psychological design.

N. D. Naplatanov lists the following among the main principles involved in designing man-machine systems.

1. Proportionate and successive adherence to optimum factor correlations between the main elements of the system in a dynamic mode.

2. Redistribution of volume and nature of functions among the main elements of the system.

3. Provision for mutual coordinat n of main parameters and elements of the system in the information, psychophysiological, and economic-technical aspects.

4. Dynamic regulation of level of centralized control.

The possibility of taking into consideration contradictory factors and requirements referable to different elements and subsystems is an important distinction of the systems approach. One proceeds from the goal-oriented function of the system in solving this problem (which is, in principle, multicriterial and multivariant).

Sin e computers were designed to help man, development of dialog between man and computers results in more natural forms of communication in man-machine systems, use of standardized, free language forms (algorithm languagues) that are inputted visually, verbally or by touch.

The systems approach to psychological analysis of interaction between man and machine, methods of studying the psychological structure of operator performance and the structural-psychological conception of analysis and synthesis of IDE constitute the theoretical foundation for preparing practical recommendations on IDE design. Applied work is being pursued in accordance with the third assignment of CEMA project 1-37.IV.

This includes development of methods for engineering psychological design of IDE for technological automated control systems of different levels and sectors of industry. This work was assigned to the Central Scientific Research Institute of

Complex Automation (Moscow). Extensive work is being done at the Leningrad Electrical Engineering Institute on refinement of symbol systems used on displays and methods of training operational personnel to work with displays. Studies of procedural and rhythmic-time structure of dialog interaction between man and computers occupy a significant place; these studies are being conducted by the State Construction Office for the Design of Calculators (Leningrad).

Engineering psychological requirements pertaining to means of output of data from YeS computers were formulated as a result of the work done by the Leningrad branch of the All-Union Scientific Research Institute of Esthetics in Engineering. In the future, these findings, along with the results of studies pursued at the Higher Mechanics and Energy Institute (Sofia, People's Republic of Bulgaria) and Institute of Psychology, USSR Academy of Sciences, could be used as material for the CEMA standard.

Some of the results of studies pursued on project 1-37.IV have already found practical applications.

The Institute of Psychology, USSR Academy of Sciences and All-Union Scientific Research Institute of Esthetics in Engineering have developed and introduced recommendations dealing with organization of the labor of dispatchers of the Ural Unified Power System. The technical and economic effect from adoption of the first phase of the engineering psychological design constituted about 150,000 rubles per year. The expected effect of making full use of the results of research will be over 500,000 rubles per year. The Central Scientific Research Institute of Complex Automation, Institute of Psychology of the USSR Academy of Sciences and Institute of Automation (Kiev) have developed and introduced several engineering psychological designs of operator stations at electric power plants: TETs-21 of Mosenergo [Moscow Regional Administration of Power System Management], Staro-Beshevskiy GRES, Chigirinskiy GRES. The overall economic effect of this work constituted more than 1 million rubles per year.

The All-Union Scientific Research Institute of Esthetics in Engineering and Institute of Psychology, USSR Academy of Sciences, developed an experimental mockup of a console for the traffic control system in Moscow, which is being introduced in our country for the first time. The expected effect of following engineering psychological recommendations in this system will be about 300,000 rubles per year.

The high efficacy of making practical use of engineering psychological recommendations dealing with organization of labor in wider scale occupations, such as instrument control workers referable to chemical units, lathe operators, assembly workers, has been convincingly demonstrated on the example of the work of Yaroslavl' State University at the Yaroslavl' Tire Plant, that of the All-Union Scientific Research Institute of Esthetics in Engineering at the Shchekinskiy Chemical Combine, that of Moscow State University at the Moscow Transformer Plant, and others. The time within which the engineering psychological designs were reimbursed averaged about 6 months.

The scientists of the People's Republic of Bulgaria, GDR, Polish People's Republic and CSSR have made considerable strides with respect to introducing the results of engineering psychological research into the national economy of their countries. In particular, Polish psychologists and ergonomists have made a large contribution to improvement of production by the instrument-making industry; Bulgarian scientists developed several engineering psychological designs for man-machine systems in the field of transportation. The scientists and specialists of GDR and CSSR did much in the area of psychological analysis and rationalization of labor in enterprises of the chemical, textile, wood working industries, as well as in machine building and energy.

Practical use of the results of engineering psychological research, made in the course of work on project 1-37.IV, shows that the economic effect from introduction thereof constitutes an average of 80,000-150,000 rubles per year per technological automated control system. If we consider that there will be several thousand such systems by 1985, the overall annual effect of using the results of psychological research could amount to hundreds of millions of rubles.

Engineering psychology is called upon to play an important role, not only in refining control of individual technological units, complexes and enterprises, but sectors of industry; in other words, in extending the knowhow accumulated on the example of technological automated control systems to large-scale organizational automated control systems.

In a modern organizational automated control system the daily intensity of the flow of processed information constitutes several million symbols. For a number of such systems, engineering psychological recommendations have been developed and introduced to organize and refine the processing of these enormous flows of information.

Work dealing with preparations for changing from mechanized to automated processing of documents without loss of information essential to making managerial decisions is of special importance [8].

Thus, engineering psychology is involved in solving one of the most important problems of building of communism and socialism, that of improving the immediacy of control of the national economy, growth of efficiency and quality of labor.

The experience of working on CEMA project 1-37.IV, "Development of Engineering Psychological Requirements Referable to Equipment for Displaying Information to Operators," has demonstrated the great effectiveness of integrating the efforts of scientists and specialists of socialist nations in the area of engineering psychology.

It is imperative to provide for an even wider scale of such successful collaboration in this field in the next five-year plan.

In our opinion, in planning future joint work, one should concentrate, first of all, on continued development of Marxist-Leninist systems methodology, strengthening the theoretical bases of engineering psychology, preparing a long-term forecast of development of this branch of science under socialism. It is important to refine methods of psychological analysis of work processes, to work on problems of multi-level adaptation of man and machines in control systems, psychological principles of transmitting information to operators and effective use of computers in cognitive processes and control. Optimization of information-related interaction between people who make joint decisions for the purpose of intensification of solutions of complex intellectual problems in the area of control [management], science and technology constitutes a special group of theoretical and applied problems.

It would be desirable to integrate work in the area of training specialists in engineering psychology, including scientist researchers of the highest qualification and administrators of engineering psychological designs.

Joint development of designs of psychological services in socialist countries will make it possible, in the future, to coordinate more efficiently the recommendations, norms and standards pertaining to psychological aspects of labor safety, design of machines, components, instruments, computers, control systems, as well as to improve within a very short period of time the supply of engineering psychology and ergonomics laboratories with the latest, most refined equipment.

In addition to solving new problems, even broader introduction of the results of joint studies pursued in the years of the current 5-year plan into the national economy of socialist countries may constitute an important objective of multilateral collaboration in 1981-1986.

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*Translator's note: TP could refer to Freight Train or Commercial Port.

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PHYSIOLOGY

PATTERNS OF PERCEPTION OF VISUAL SIGNALS

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[Article by A. N. Lebedev, submitted 11 Oct 79]

[Text] Formulation of the Problem

The perception process is inconceivable without operations of comparing presented signals to those stored in memory. The hypothetical mechanisms of comparison are being studied in many laboratories. Schneider and Shiffrin [7] published the most recent special survey of such studies. Ultimately, these authors proposed a system of equations that best explain the broad range of accumulated experimental data, including their own, but yet did not cover all of them.

In the first place, they did not include in their system the link between duration of perception and short-term memory span. As a result of analysis of numerous data, Cavanagh [5] discovered a certain link of this sort.

In the second place, the above system of equations does not include the parameters of neurophysiological processes upon which perception is based.

Our objective was to fill this gap, compose a system of simple equations and find a generalization of the known patterns of perception.

First, we must mention the inherent distinctions of the experiments in question [4, 7]. A certain number of visual symbols is presented to the subject, for example, digital ones, after instructing him to retain them for a short time. The subject himself limits the time of exposure of the symbols to be retained. Then, after a warning signal, several frame [still, image?] or test symbols are presented simultaneously.

According to the instructions, the subject depresses one button, as fast as possible, if the frame symbols do not include a single labeled one, i.e., one that was retained before, otherwise he depresses another button. The unlabeled symbols are also called distractors. The situation is called negative if all of the frame symbols are distractors. Otherwise the situation is positive. Details about these tests were described elsewhere [4, 7].

It is assumed that before pressing on a button the subject successively compares each labeled signal to each frame signal until he is sure that all of the frame symbols are distractors (in a negative situation), or until he detects a labeled signal among the distractors (in a positive situation).

Comparison time as a function of number of frame and labeled symbols must be determined.

For this purpose, we measure the time between presentation of frame symbols and the subject's depression of the button, i.e., the discrete or latency period of the reaction. Part of the latency period is unrelated to the number of frame and labeled symbols, and it is called the constant, or nonreducible lag.

The rest of the time is a function of number of labeled and frame symbols. This is the comparison time. The problem is to find a theoretical definition of the sought function.

The simplest hypothesis is that comparison time is proportionate to the number N of all necessary comparisons of frame and labeled symbols. Its lowest value equals the product of number m of labeled symbols multipled by number K of frame symbols, if each, as it is generally believed, is successively compared to another, one by one.

Taking these circumstances into consideration, we find that comparison time in a negative situation is determined by the formula:

$$t_{neg} = Nt \qquad (1)$$

and in a positive situation, by:

$$t_{pos} = \frac{N+1}{2} \qquad (2)$$

where t is the duration of one operation of comparing a frame and labeled symbol.

The hypotheses concerning functions of types (1) and (2) were first expounded in [6].

Schneider and Shiffrin [7] tested the above hypotheses in their experiments and, strictly speaking, rejected them, because the experimental values for comparison time were above the minimum level predicted by formulas (1) and (2). For this reason, they proposed their own system of equations. The following turned out to be the most accurate:

$$t_{neg} = amK + b(mK - K + 1) + c(mK - m + 1) + t_n \qquad (3a) \qquad (3a)$$

$$t_{pos} = a\left(\frac{mK+1}{2}\right) + b\left(\frac{mK-K+2}{2}\right) + c\left(\frac{mK-m+2}{2}\right) + t_p \qquad (3б) \qquad (3b)$$

where a, b, c, t_n and t_p are constants found in the experiment.

Table 1, which is taken from [7], lists the values for the constants according to the data of two teams of researchers.

[redacted]

Table 1. Constants in the equations of Schneider and Shiffrin

Source	Constants, ms					Deviation, ms
	t_n	t_p	a	b	c	
Schneider, Shiffrin [7]	623	552	13	45	0	21,3
Briggs, Johnsen [4]	569	500	38	29	0	23,7

Judging by the low standard deviation of actual values from the predicted ones, the equations are rather accurate, but they are cumbersome, contain many constants and do not have clearcut neurophysiological bases.

Expounded Hypothesis

Our solution was based on known data [1, 2] concerning the relation of coherent, narrow-band oscillations of neuronal activity to mechanisms of reflex activity and memory. We assumed that, at some stages of storage, perceived signals are coded by a diversity of phases of narrow-band coherent oscillations of neuronal activity. The phase combinations, which form a system, store a certain portion of the information.

The beginning of formation of such a system coincides with the time of primary positivity of cortical evoked potentials, i.e., with the very first reactive discharge of many central neurons localized in different parts of the brain. The first wave of coordinated neuronal activity appears. It is followed by several more waves, i.e., coherent neuronal discharges. They all depend on the first discharge and form a chain of successive discharges, or a wave packet, since the coherent discharges of numerous [or a set] of neurons are related to the slow, wave-like oscillations of potentials.

Not all neurons are fired at the time of primary positivity. This is known. Some of the neurons are first fired at a later time, for example, at the moment of secondary positivity. These primary discharges evoked by afferent signals form the beginning of a second wave packet, the second chain of successive discharges.

There are neurons that first show discharges at an even later time. They form the beginning of the third wave packet, etc.

There is an interval of at least 0.01 s between appearance of different packets. This corresponds to the time of relative refractoriness following each neuronal impulse, as well as time of summation of postsynaptic potentials causing neuronal discharge.

The minimum intervals between similar phases of different waves within the same wave packet are of the same duration.

The diversity of phase combinations storing information about signals impressed in memory depends not only on the absolute value of the above-mentioned relative refractoriness, but the absolute period of oscillations forming the system of information storage.

It is known that the waves of bioelectrical activity have different periods, and that, according to the autocorrelograms, attenuation also proceeds at a different rate. Alpha waves persist for the longest time. Probably, expressly they implement storage of information in memory. The periods of alpha oscillations constitute a mean of 0.1 s, differing slightly from one another. M. N. Livanov was the first to attribute the phenomenon of alpha spindles, i.e., pulsation of frequencies in the alpha range, to such differences.

Each system that stores information has its own frequency within the alpha range, and all wave systems with different frequencies that are formed under the influence of the same perceived signal store information about this signal. As a result of frequency interference, the phase combinations are repeated with pulsation [beat] periods. The closest frequencies form pulsations with the longest periods, up to 1 s. Calculation of this value is described below. More detailed information about the mechanisms of stability of alpha waves and their mathematical model is given in [1].

Such is the hypothetical mechanism of storage of information by packets of alpha waves. Let us now turn to the mechanism of comparing perceived signals to those stored in memory. Both are coded by specific phase combinations, i.e., specific wave patterns. The activity of neuronal systems that store information changes in a wave-like fashion, and it is only at specific points in time that reactive wave patterns corresponding to those stored in memory are put together. The time of uniting similar wave systems corresponds to the time of successful comparison of presented information to that stored in memory, i.e., the time of recognition of delivered signals.

If there are several standard signals, i.e., those stored in memory, all of them are compared to each of the presented signals successively, one by one, within one pulsation period. The successiveness of comparisons is attributable to the independent oscillations of different systems.

At the same time, we cannot rule out the possibility of parallel comparisons. If there are several signals perceived and each of them is compared to the standard signals independently, the number of such parallel procedures of comparison does not exceed the number of all signals perceived simultaneously. Each procedure includes the operations of successive comparison of signals stored in memory to each of the presented signals, as noted above.

These hypotheses can be submitted to experimental testing.

Experimental Testing of Hypothesis

Span of short-term memory: Signals stored in short-term memory are coded by packets of coherent alpha waves. The tighter the waves are packed, the shorter the intervals between adjacent phases of waves with the same period and the more signals can be retained in short-term memory.

If M is the number of signals in the alphabet, the span of short-term memory can reach value H, which is defined by the equation:

$$H = \left(\frac{1}{\alpha\rho} - 1\right) \log_M \left(\frac{1}{\alpha\rho} - 1\right), \qquad (4)$$

[redacted]

where α is the mean frequency of spatially coordinated oscillations of alpha rhythm storing information about retained signals, α = 10 oscillations/s; ρ is the time between adjacent phases of oscillations, which equals the relative refractoriness following each neuronal impulse, ρ = 0.01 s.

This formula predicts the maximum diversity of packets of waves storing information about perceived signals.

We checked the conclusion that the span of short-term memory is limited together with I. A. Komarova; we used an epidiascope to exhibit to subjects, for a short time, lines consisting of random, equally probably digital or alphabetic symbols, as well as random syllables of the consonant-vowel-consonant type. The subject recalled each line after it was presented for 2 s. Symbols called with indication of their position and meaning were considered to be correctly recalled. A total of 10 people participated in these experiments, and each of them recalled a total of 30 lines of symbols. The mean data on correctly recalled signals, syllables and symbols, are listed in Table 2. The standard deviations from means constituted 12-18% of the mean value for each subject.

Table 2. Short-term memory span as a function of signal alphabet

Signal	Alphabet of signal	Number of signals		Memory span, bits
		presented	recalled	
Syllables	4000	3	2,3	28
Letters	32	7	5,6	23
Digits	10	9	6,3	21

The experimentally found values for span of short-term memory do not exceed the theoretical range indicated in equation (4). Spans calculated for artificial syllables are closest to this range.

Consequently, artificial syllables similar to the structure of the subjects' native language are the most convenient and most economical carriers of information that provide for error-free recall. It is more economical and reliable to use syllables, rather than digital or letter codes, wherever it is necessary to name events or objects, for example, in numbering transportation means.

Experience has shown that symbols that represent a short alphabet are recalled more poorly than prediced by theory. Nevertheless, the order of distribution of symbols according to recall is consistent with the forecast defined in equation (4): the larger the alphabet of symbols stored in memory, the fewer symbols are correctly recalled.

In the next series of experiments, we compared the number of all signals recalled without exception, including incorrectly recalled ones, and the number of correctly recalled symbols. The instructions were the same as before: recall the exhibited lines of symbols as accurately and completely as possible. A total of 83 people ranging in age from 18 to 25 years participated in these tests, and each of them recalled 20 different lines each consisting of 10 digital symbols. The line of symbols was delivered either visually for about 3 s or orally (they were read out by the experimenter one after the other within 3-5 s). As in the preceding tests, the subjects started to recall a line immediately after presentation, and not any sooner.

Table 3. Short-term memory span

Type of memory	Number of recalled digital symbols			
	overall		correct only	
	mean	standard deviation	mean	standard deviation
Visual	8,44	1,04	6,85	1,04
Auditory	8,32	1,19	6,74	1,27

It was found that, in this case too, the experimentally determined short-term memory span did not exceed the theoretical limit of 29 bits, or 8.6 decimal symbols. The number of all symbols recalled, including incorrect ones, coincided almost exactly with the theoretical limit (Table 3).

Duration of comparison operation: Frame and labeled signals, i.e., those stored in memory, are compared one by one because of the undulant fluctuations of neuronal activity. Probability p of instantaneous (with no lag) comparison of a labeled signal to a frame one is expressed as follows:

$$p = \frac{e^{-\alpha\rho}}{\alpha K}, \tag{5}$$

where the numerator indicates the probability of excitable state of neurons forming an alpha wave with their activity and the denominator shows the number of all equally possible comparison operations at a given moment.

It is known that alpha waves have slightly different periods, because of which there is pulsation, or "spindles" of alpha rhythm.

The pulsation period is determined by the following equation, with accuracy down to the smallest interval of time by which alpha waves differ, i.e., with accuracy to the relative refractoriness:

$$T = \frac{1}{\alpha^2\rho}. \tag{6}$$

All of the frame and labeled symbols in short-term memory (in the system of wave packets) will have time to be compared to one another within one such period. The intervals between adjacent comparisons are determined by the following equation:

$$t(K, m) = T(1 - p^K)\frac{1}{1-p}\int_{x=p}^{x=1}(1-x)^K dx, \tag{7}$$

and the solution of this equation leads us to the sought formula that determines the duration of one comparison operation:

$$t^{*} = T\,\frac{(1-p^{K})\,(1-p)^{K}}{K+1}. \tag{8}$$

This formula predicts quite accurately, as it was previously determined [1], choice reaction time as a function of number m of equally possible alternative signals with $K = 1$.

If the comparison operations occur in parallel and the number of parallel processes equals the maximum possible number of symbols in short-term memory, the mean time for one comparison operation is reduced to:

$$t = \frac{t^{*}}{H}. \tag{9}$$

In the general case, taking into consideration subjective probability p_m of expectation of labeled signals m in alphabet M of all signals, the time of the comparison operation is set by a function that ensues from the original equation (7):

$$t = p_m t(K, m) + (1 - p_m)\, t(K, M).$$

In this case, it is assumed that the subjective alphabets of expected signals may change in the course of the test from a value of m tc a value of M.

Duration of matching [comparing] procedure: In order to match a presented, i.e., frame, symbol with a specific labeled symbol corresponding to it that is stored in memory, one to a number K operations of comparison are required, where K is the number of all frame symbols. Everything depends on the position of the test frame symbol in the series of other symbols similar to it. Ultimately, the maximum possible number of comparison operations reaches a value that is determined by the equation:

$$N = \sum_{i=1}^{K} mi = \frac{mK(K+1)}{2}, \tag{10}$$

where i is the position number of the test frame symbol.

Now we can find the duration of the entire comparison procedure. For this purpose we shall substitute in equations (1) and (2) the values from equations (9) and (10), i.e., the duration of one comparison operation and total number of such operations.

We used the data in Table 1 to check the theoretical calculations.

In our calculations, we took into consideration the typical mean frequency of human alpha rhythm and relative refractoriness indicated above, as well as the mean short-term memory span expressed in digital symbols (which were those mostly used in the experiments), which equals $H = 7.7$ symbols, according to the data of many authors summarized in [5].

All three parameters are the only constants in our equations; they have clear physiological and psychological meaning and, what is the main point, they can be submitted to independent experimental verification in neurophysiological and psychological experiments.

The results of analyzing the system of equations are listed in Table 4.

Table 4. Theoretical and experimental estimates of comparison time (ms) for labeled and frame signals in positive and negative experimental situations

Source	Number of frame signals								
	1			2			4		
	number of labeled signals								
	1	2	4	1	2	4	1	2	4
	Negative situation								
[7]	0	58	174	13	129	361	39	271	735
[4]	0	67	201	38	172	460	44	382	918
Mean of [4, 7]	0	62	187	26	150	410	42	326	826
Theory	0	39	156	31	148	404	93	322	824
	Positive situation								
[7]	0	29	87	6	64	180	20	136	368
[4]	0	34	100	19	86	220	47	145	355
Mean of [4, 7]	0	32	92	12	75	200	33	140	361
Theory	0	30	97	20	88	218	50	165	412

The data listed in the table are not in contradiction with the hypothesis under discussion. The predicted comparison time deviates by a mean of only 24.7 ms from the experimental estimates.

Discussion

Cavanagh's constant: By solving the system of equations (2) and (6)-(10) with parameters $K = 1$ and $m = H$, we can find the time of comparison of signals in short-term memory to presented frame signals in a positive situation (frame signal--labeled):

$$t(H) = \frac{\left(\frac{1}{4} + \frac{1}{4H}\right)\left(1 - \frac{1 - \alpha\rho}{H}\right)^2}{\alpha^2\rho}. \tag{11}$$

When the span of short-term memory exceeds three units, this time is about 0.25 s, i.e., it equals the constant demonstrated by Cavanagh [5] in his analysis of numerous experimental data.

Link between rate of retrieval of signals from memory and memory span: The increment of comparison time with successive increase in number of marked signals per symbol is generally considered signal retrieval time, or signal search time in short-term memory. If we divide the above-determined constant (11) by the number of increments, we shall find the sought time:

$$t' = \frac{t(H)}{H-1}. \qquad (12)$$

The theoretical and experimental data [5] are summarized in Table 5.

Table 5. Link between short-term memory span and time of search of signals in it

Nature of signal	Span, symbols	Search time, ms/symbol experim.	theory
Syllables	3,4	73	73
Random shapes	3,8	68	66
Geometric figures	5,3	50	48
Words	5,5	47	46
Letters	6,35	40	40
Colors	7,1	38	36
Digits	7,7	33	33

Table 6. Comparison time (ms) as a function of number of labeled symbols and memory span in a positive situation

Number of symbols	Experiment	Theory, span 6,7	7,1	7,7	Number of symbols	Exper.	Theory, span 6,7	7,1	7,7
2	35	34	32	29	5	150	151	142	131
3	75	73	69	64	6	190	189	178	164
4	115	112	106	98					

Sternberg's function: The data in Table 5 convince us of the validity of the system of equations, with which we can predict the experimental data obtained in [6].

After substituting $K = 1$ in the system of equations, we shall obtain (in the same terms):

$$t_{pos} = \frac{m+1}{4H}\left(1 - \frac{1-\alpha\rho}{m}\right)^2 \qquad (13)$$

The values of the determined function are listed in Table 6, along with experimental estimates, and hence the short-term memory span of Sternberg's subjects most probably constituted 6.7 symbols. This is in the known range of values, although it differs from the general mean calculated in [5].

Table 7. Comparison time (ms) as a function of number of repeated presentations of each combination of frame and labeled signal

Comparisons m	Repetitions i					Comparisons m	Repetitions i				
	1	2	5	10	15		1	2	5	10	15
1	0	0	0	0	0	4	112	81	31	6	1
2	34	24	9	2	0	5	151	109	41	8	2
3	73	53	20	4	1	6	189	136	51	10	2

Sternberg discovered that the function in question was about the same for both a positive and negative situation in his tests. This phenomenon could be attributed to erroneous actions of subjects, to which attention is called in [7]. However, there is more to the problem.

Comparison dynamics: We know from [7] that comparison time is drastically reduced if the marked symbols remain constant, the same, in the course of the tests. Shiffrin and Schneider called this decline a transition to automatic mode of comparison, but they did not offer any hypotheses concerning the dynamics of this process.

We know of several learning equations. We took one of them [1]. It is an equation of the following type:

(14)

where p_i is the probability of occurrence of a learned event after the ith repetition of the comparison operation and p_1 is probability determined with equation (5). Let us indicate that the value $s \cong 1$ corresponds to probability of retaining in long-term memory all of the contents of short-term memory after single reception of information. According to the rate of retention of digital symbols [1], probability $s = 0.15$. With $s = 0.15$ and $H = 6.7$, we have the findings listed in Table 7.

Conclusions

A new system of equations of perception, which ensues from neurophysiological premises contained in [1, 2], explains the main patterns of comparison of perceived signals to those impressed in memory. For the first time, it was possible to generalize diverse data [4-7] concerning the rate and volume of perception with two constants that have overt physiological meaning: period of alpha rhythm which averages 100 ms and relative refractoriness of 10 ms.

The following perception patterns were demonstrated:

1. The volume of perception (short-term memory span) is determined by the ratio of period of coordinated oscillations of neuronal activity to minimum difference in their phases, which equals relative refractoriness and does not exceed the values specified in equation (4), i.e., about 30 bits.

2. The duration of the variable perception lag depends on the period of frequency pulsation in the alpha range and does not exceed the value specified in equation (6), i.e., 1 second.

3. Duration of operations of comparing signals that are perceived and stored in memory is functionally related to their number and parameters of oscillations of neuronal activity in accordance with equation (8).

4. The time of signal search in short-term memory and its span are functionally interrelated in accordance with the solution of equations (9)-(13).

The direction of our search was prompted, to some extent, by the problems of engineering psychology defined in [3]. We believe that this system of patterns of visual perception will be useful in solving a number of problems of engineering psychology.

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AUTOMATIC ANALYSIS OF COLOR VISION

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[Article by Ye. N. Sokolov, M. M. Zimachev, Ch. A. Izmaylov, N. P. Brusentsov, S. P. Maslov and H. Ramil Alvares]

[Text] Evaluation ["diagnostics"] of human color vision is used in occupational screening in the most varied branches of industry: chemical industry, polygraphy, transportation and others. In developing methods for such evaluation, one must take into consideration two aspects: simplicity of practical use of a method and achieved accuracy of color vision characteristics.

Accuracy of analysis is determined by the resolution capacity of a method. Since diagnostics is a classification process, the more classes there are for the distribution of subjects, the more accurate the diagnostic method. In this sense, maximum accuracy of a method consists of the possibility of differentiating between any two subjects.

At present, there are developed and tested methods, which can be compared to one another on the basis of how they combine simplicity and accuracy.

The simplest and most widely used method is evaluation with the use of tables. It consists of classifying a subject as belonging to one of four types, according to his color vision distinctions: 1) normal trichromats, 2) anomalous trichromats, 3) dichromats and 4) monochromats. The second and third types are each subdivided into three forms: deuteranomalopes, protanomalopes and tritanomalopes for the former, deuteranopes, protanopes and tritanopes for the latter.

This classification takes into consideration only very drastic variations in color vision. In the Soviet Union, polychromatic tables were developed in the laboratory of Ye. B. Rabkin, and they permit finer differentiation between two forms of anomalous color vision, deuteranomalopia and protanomalopia [4]. With these tables, one can make a distinction between three degrees of anomaly for each of these forms: C--mild, B--moderate and A--severe.

The polychromatic tables are very simple to use; 10 min are sufficient for an experienced examiner to make a diagnosis. This is a significant advantage of the method. Its flaw is, primarily, that the accuracy is low. Even the most refined tables of Ye. B. Rabkin permit classification in only 11 classes. This is a rather rough evaluation, as compared to the information about individual distinctions of color vision that are known in the science of color and which practice requires. Moreover, the method of polychromatic tables requires individual testing, and there is no guarantee against simulation.

Anomaloscopy is another classification method used in practice. It involves the use of special instruments, anomaloscopes. The subjects must compose Rayleigh's color equation (535+650 = 589 nm and 470+517 = 490 nm) [14] on two halves of a test field.

The subjects are classified according to the proportion of addends in the left part of the equation. The anomaloscope is so designed that this ratio is equal to about one for a normal subject. This ratio may be greater or lesser than one, depending on the form of anomaly. The so-called anomaly coefficient is obtained by standardizing this ratio for a given subject according to the mean statistical ratio for the norm. One can plot a partially ordered scale from the value of anomaly coefficient, having selected arbitrarily certain intervals of values as indicators of types of anomaly. For example, in the manual of Wyszecki and Stiles (1967), it is suggested that subjects with a ratio of more than 1.5 be considered as deuteranomalopes and with less than 0.75 as protanomalopes, etc.

Anomaloscopy is a much more refined method of evaluation than polychromatic tables; however, the coefficient of anomalousness [or anomaly] alone is not enough to subdivide subjects within each class; for such subdivision, one has to take additional measurements of spectral sensitivity, or color discrimination function, etc. In addition, like any threshold measurement, anomaloscopy involves some rather labor-consuming procedures, which must be performed in order to obtain statistically reliable results. For this reason, in practice one generally makes one or two tests, from which one can determine the form of color vision rapidly (although with considerably less accuracy).

Anomaloscopy is performed individually, and this is inconvenient for mass-scale studies. The advantage of anomaloscopy is that there can be no simulation on the part of the subject; for this reason, it is recommended that an anomaloscope be used in practice along with the polychromatic tables.

In addition to anomaloscopy and polychromatic tables, color vision is evaluated by means of color mixing functions [2], on the basis of which one can determine the different aspects of human color vision with greater accuracy. The main element of this method is that the observer composes equations of color confusion from which a spatial model of confusing equally bright colors, the so-called color diagram, is constructed, which permits quantitative evaluation of the sensitivity of the eye to barely noticeable differences in wave length, estimation of color complementarity function, color opposition, etc. It must be noted that the color [chromatic] diagram plotted from equations of color confusion does not permit unequivocal determination of color differences. The relationship between the metrics of color confusion and metrics of minor and major color differences has not yet been sufficiently studied to interpret the results of different tests, and efforts to solve this problem have not yet gained wide recognition [12, 16]. However, even the information that is contained in the chromatic diagram makes it possible to make a very fine classification of different forms (and within forms) of color vision.

But, in spite of the adequate accuracy of this method, it is not in wide use because of the difficulty involved in composing the equations of color confusion, which serve as the base data. They can be obtained under special laboratory conditions, after a lengthy and complicated observation procedure, and testing only one observer each time.

Thus, we find that simple methods of evaluation yield little information about the color vision of an observer, and for this reason do not permit making a fine classification, while the informative methods are based on inconvenient and complicated procedures of threshold measurements.

Consequently, the task is to develop a testing method that would be simple to use and yield sufficient information about the observer's color vision. We propose here a new approach to resolving this task, which is based on a spherical model of color discrimination, to construct which the method of multidimensional scaling is used.

Evaluation of Color Vision on the Basis of a Spherical Model of Color Discrimination

The new approach to evaluation of color vision of man is related to analysis of ratings of supraliminal color differences by the method of multidimensional scaling [7, 8]. Analysis consists of representing the set of colors to be evaluated in the form of configuration of points in geometric space. The distances between points are set as a certain monotone function of initial differences between stimuli. This means that very mild restrictions are imposed on the initial evaluations, and in particular it is sufficient for them to represent at least a sequential scale (for example, simple ranking of interstimulus differences). For this reason, the actual testing procedure can be very simple.

Having obtained from the testing ratings of all paired differences between stimuli, special mathematical procedures are used to calculate the positions of the points in Euclidean space so that the distances between points conformed with the initial evaluations of differences. Projecting the obtained configuration in a smaller space [space with less dimensionality], one obtains the minimum possible (from the standpoint of retention of conformity between interpoint distances and initial evaluations) space, the axes of which are explicitly interpreted as the main subjective characteristics determining the initial set of evaluations. The remarkable advantage of multidimensional scaling is that "two conditions that are nonmetric in content--monotony and minimal dimensionality--make it possible to gain complete metric information from ordinal data" [17, 18].

A number of studies of color discrimination using methods of multidimensional scaling [3, 5, 6] demonstrated that the matrix of wide supraliminal differences between color stimuli contains virtually all of the information about human color vision. As a result of these studies, a geometric model of color discrimination was constructed, in the terms of which one can describe quantitatively the most varied phenomena of color perception.

The model consists of a sphere in three-dimensional Euclidean space (Figure 1), each point of which characterizes a specific color. The three mutually orthogonal axes in space are interpreted as three opponent systems (red-green, blue-yellow and white-black). The chromatic opponent axes form the equatorial plane of the sphere. Monochromatic colors form a curvilinear trajectory on the sphere, which ends with purples. The pole of the sphere represents white. The horizontal angle characterizes the color tone and vertical angle the color saturation, while the subjective difference between two colors is determined by the central angle of the small arch of the large circle that connects the two points on the sphere corresponding to these colors.

It is more convenient to depict the spherical model graphically in the form of projection on the equatorial plane X_1X_2, as illustrated in Figure 2a, where the thin solid line connecting the small dots shows the trajectory of spectral colors from 440 to 660 nm, which was obtained as the mean for three subjects with normal color vision. The base data for these subjects were taken from the work of Boynton and Gordon [10], according to which the spherical model was constructed by the method of multidimensional scaling, as described in [3]. The trajectory of spectral colors in Figure 2a arbitrarily ends at the small arc of the large circle (dash line), which characterizes the position of maximally saturated purple-crimson colors. The part of the chromatic sphere limited in this way (which we shall call the spherical chromatic diagram) constitutes the entire set of equally bright colors that the subject sees under standard viewing conditions. Just like the traditional chromatic diagram in coordinates XY, the spherical diagram describes the general structure of subjective chromatic space.

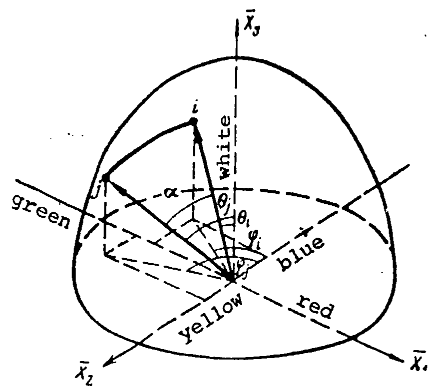


Figure 1.
Appearance of spherical model of color discrimination. Points i and j represent pairs of colors on the surface of the color sphere; α_{ij}, Θ_i and ϕ_i are the angular characteristics of points on the sphere, which are interpreted as color discrimination, color saturation and color hue [tone], respectively

As shown in [3], one can calculate all of the main color functions characterizing the sensitivity of the observer's color analyzer, in particular, the function of saturation, opponent functions, functions of first threshold of color discrimination, on the basis of the spherical model of color discrimination. A comparison of chromatic functions estimated within the framework of the spherical model of color discrimination to analogous ones measured by threshold methods indicates that these estimates are just as accurate as threshold data.

Moreover, it was found possible to obtain some chromatic characteristics on the basis of the spherical model that would have been quite difficult to measure by threshold methods. We refer, for example, to the function that describes in terms of wavelengths sensitivity to a barely noticeable change in color tone only or saturation alone for monochromatic colors.

Thus, the spherical model makes it possible to describe an observer's color vision both in general and with regard to some aspect of color vision. In this sense, the spherical model of color discrimination is analogous to both the international XY system and other popular models of color discrimination, for example the system proposed in [13, 14].

However, as compared to all models proposed thus far, the spherical model of color discrimination has a substantial advantage, which is the extreme simplicity of the procedure of ranking differences, which is used to obtain base information. This advantage is of decisive significance to classification of subjects according to form of color vision, with which we are concerned here, as well as to a number of other applied problems.

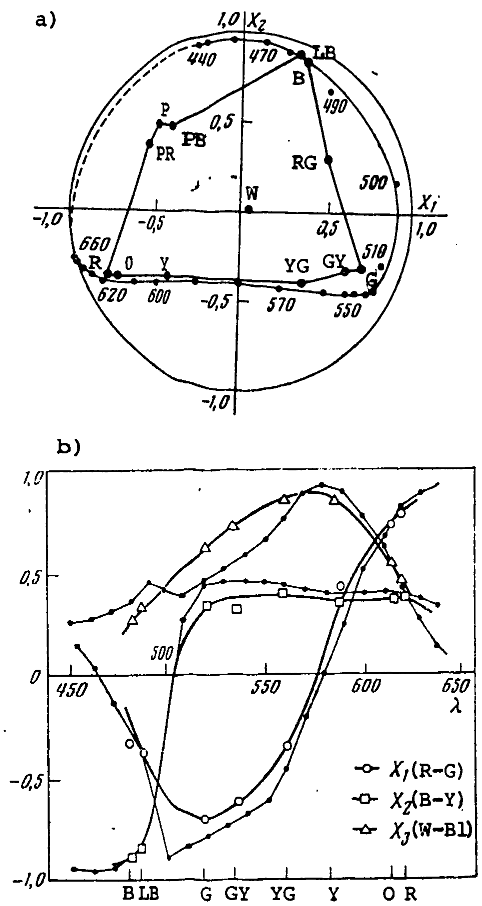


Figure 2.
Spherical model of color discrimination for normal trichromatic vision

a) projection of chromatic sphere on equatorial plane X_1X_2 (spherical diagram of color; described in text)
b) opponent color functions calculated within the framework of the spherical model for monochromatic colors (the dots connected by thin lines) and nonspectral colors (circles--red-green function, squares--blue-yellow and triangles--white-black). Under the graph on the x-axis are the positions of nonspectral colors in the spectrum according to dominant wavelengths

As shown by experience, it is a rather easy task to actually construct a spherical model of color discrimination, i.e., to assess differences between colors in ranks. Unlike the traditional approaches to construction of a system of color specification, where the main objective is to obtain as accurate as possible base data, the proposed approach imposes very mild restrictions on base data. All of the difficulty and labor are transferred to the experimental section while processing the base data. Analysis of the matrix of differences, construction of the spherical model and calculation of chromatic functions--all this involves, of course, a large amount of complicated mathematical procedures that can be performed only on modern computers.

The proposed method for evaluation of color vision has another advantage: it can be used to test stimuli with a complex spectral composition, rather than monochromatic. This permits more comprehensive description of the general structure of chromatic space, using both colors close to monochromatic and those with little saturation, including white. Technically, this means that one can use luminophore instruments, the control of which can be readily automated, as sources of stimulation.

Use of this approach on a modern technical basis, with the use of digital computers and a color television has made it possible to automate, to a large extent, the procedure for individual testing, concurrently with testing of a group of subjects.

Key:

P)	purple	W)	white
PB)	purple-blue	R)	red
PR)	purple-red	O)	orange
B)	blue [dark]	Y)	yellow
LB)	light blue	YG)	yellow-green
RG)	red-green	GY)	green-yellow
G)	green	Bl)	black

An automated system of group analysis of color vision was designed on the basis of equipment developed by the computer laboratory of the Scientific Research Computer Center at Moscow State University for the computerized teaching system, Nastavnik [1], to which a digital-computer-controlled Raduga-701 color television was added. The equipment of the Nastavnik system contains 27 miniterminals which operate in a time-sharing mode with a small Setun'-70 digital computer. A specialized Setun'-72 computer is used for direct contorl of the miniterminals; it performs commutation and buffering of communications, as a result of which the system's reactions to signals delivered from the miniterminals are quite rapid (each terminal is interrogated 46 times per second).

The miniterminals make it possible for interaction with the Setun'-70 computer by means of transmission of symbols, for which purpose each has a keyboard with 11 keys, and to obtain symbols outputted by the computer on a fluorescent digital display, which is the receiving organ of the terminals.

The computer controls the Raduga-701 color television by means of digital converters, which permit display on the video screen of any of 27 previously selected colors at 27 selected levels of brightness. The block diagram of the unit is given in Figure 3.

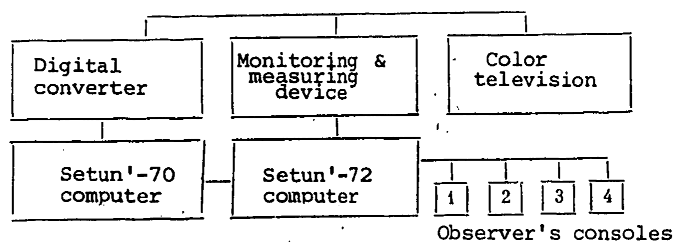


Figure 3. Block diagram of unit for automated evaluation of color vision

The program executed by the computer delivers color stimuli to subjects for the specified time and at set intervals, as well as the audio signal "attention,"prior to each presentation. It generates a pseudo-random sequence of stimuli of a specified length. The same program records the evaluations of subjects, forming information for each subject about the results of the experiment in the form of a matrix of subjective differences (Tables 4a-6a).

In order to clarify the practical aspect of the proposed method of evaluating color vision, we shall describe in detail the diagnostic tests conducted simultaneously on several subjects.

Method

1. Subjects: As subjects we used school children and students on the psychology faculty, who had no experience in direct appraisal of color differences. In view of the limited amount of publications, we shall furnish here only part of our results: averaged data referable to 15 subjects with normal color vision and averaged data for subjects with protanomalopic and deuteranomalopic color vision, as well as individual data on one trichromat (subject M. V.), one protanomalope

(subject S. A.) and one deuteranomalope (subject P. R.). At first, the evaluation of each subject was made by two methods, with the use of Rabkin's polychromatic tables [4] and the Rautian AN-69 anomaloscope. Table 1 lists the results of using traditional diagnostic methods.

Table 1. Results of examining subjects with the use of anomaloscope and polychromatic tables

Subject	Rabkin polychromatic tables	Rautian AN-59 anomaloscope, anomalousness coefficient
S. A. (left eye)	Protanomalopia, grade A	Protanomalopia, 0.22
S. A. (right eye)	Same	Protanomalopia, 0.11
S. A. (binocular)	Same	--
M. V. (left eye)	Trichromatism	Trichromatism, 0.99
M. V. (right eye)	Same	Trichromatism, 1.03
M. V. (binocular)	Same	--
P. R. (left eye)	Deuteranomalopia, grade B	Deuteranomalopia, 4.26
P. R. (right eye)	Same	Deuteranomalopia, 4.70
P. R. (binocular)	Same	--

2. Stimulation: Color flashes with complex spectral composition served as stimuli, and they were exhibited on the color television screen. The brightness of the stimuli constituted 25(±2) nit. The characteristics of stimuli in the MOK-31 system were measured with a standard calorimeter (Table 2). The stimuli were delivered successively in pairs, 10 times each. In all there were $n(n-1)/2 \cdot 10$ deliveries, where n is the number of stimuli. Duration of each stimulus was 0.3 s, the interval between stimuli in a pair was 0.5 s and between pairs it was 1.5 s. The stimuli were round, with angular size of 2°. The test was conducted after dark adaptation (5 min). In all, we used 13 stimuli that were so selected as to have the basic colors (blue [dark], light blue, green, yellow, orange, red and purple) and different degrees of saturation (from close to monochromatic to white) represented in the test. In this case, white color was close to the color of a standard source C [or S?].

Table 2. Coordinates of color stimuli in the MOK-31 system

№	Color	X	Y	λ_{eq}	№	Color	X	Y	λ_{eq}
1	Blue	0,12	0,15	480	8	Orange	0,56	0,32	615
2	Light blue	0,14	0,22	484	9	Red	0,59	0,31	620
3	Blue-green	0,20	0,34	495	10	Purple-red	0,29	0,17	558
4	Green	0,21	0,59	520	11	Purple-blue	0,24	0,14	567
5	Green-yell.	0,25	0,56	535	12	Purple	0,25	0,16	565
6	Yellow-green	0,35	0,52	560	13	White	0,31	0,32	—
7	Yellow	0,50	0,40	588					

3. Instructions: The subjects must evaluate the difference between stimuli in a pair on a scale of 0 to 9. Zero corresponds to two identical stimuli in the pair. Maximum differences (9th rank) are determined by the subjects individually in the

course of preliminary training, when all pairs of stimuli are presented once in random order. Before each pair, an audio signal, "attention" (600-Hz buzzer) was given. The reaction consists of depressing one of the 10 keys (0, 1, ..., 9) on the subject's console.

4. Base data. The results were processed in two separate stages. Primary processing was performed in the course of the test, for all participants at once, on the Setun'-70 computer. After such processing, all of the ratings of each subject were summarized on an individual triangular matrix, the element of which was the rating averaged for the number of presentations and multiplied by 10. Thus, the matrix describes for us all of the differences between stimuli, pair by pair. For each subject we obtained three separate matrices of interstimulus differences in relation to one of three observation conditions: binocular and monocular for the left eye, and monocular for the right eye. Subsequent data processing, which consisted of analysis of base differences by the method of multidimensional scaling, was performed on an M-6000 computer using a program based on the algorithm of Young and Torgerson [19].

Construction of Spherical Model of Color Discrimination

1. Dimensionality of subjective space: As a result of analysis by the method of multidimensional scaling for each matrix of differences one calculates the coordinates of points in an n-dimensional Euclidean space (n is the number of stimuli used) and characteristic roots, from which the significance of each spatial axis is assessed. Theoretically, the characteristic roots may be either positive or equal to zero. The number of positive roots indicates the dimensionality needed for each matrix of the real Euclidean space, in which one can describe without error the base data as distances between points. However, because of judgment errors made by the subjects, zero root values may change in both the positive and negative direction. For this reason, in practice, one determines the true dimensionality according to the largest positive roots.

Table 3 lists the characteristic roots for all matrices that are analyzed in this article. These data show that there is a change in decimal order of value between the third and fifth roots. Up to the third root, all of the values have four digits ["decimal" digits] or more (with the exception of the mean matrix for the deuteranomalope), whereas from the fifth root on all of the values have only three or less digits. The fourth root serves as a sort of boundary between significant and definitely insignificant axes. This shows that the subjective space of color discrimination must have at least three dimensions [measurements].

It must be noted that the value of a characteristic root per se cannot, of course, serve as an adequate criterion of minimal dimensionality, particularly in the case of noise-covered data, which usually occurs in experiments. However, one can estimate the necessary boundaries of true dimensionality from the values of the roots. Here, as in other formal analyses, the final solution depends on intrinsic [proper] interpretation of obtained data.

As we have already stated, for subjects with normal trichromatic vision, the three dimensions of space are related to three opponent characteristics of color discrimination. Of greatest significance is the characteristic root of the red-green spatial axis, followed by the one of the blue-yellow axis, while the characteristic root of the white-black axis has the lowest value; the difference between the third root and the first two is usually considerably greater than the difference between the latter (see, for example, Table 2 in [3]). The same findings are observed in Table 3. In the columns with the headings of "mean for 15 subjects" and "subject M. V.," where data are listed for normal subjects, the order of the characteristic roots is the same, from the red-green to the white-black axis.

This three-dimensional interpretation is generally found to also apply in the case of color anomaly; however, we then observe some changes that must be mentioned. In the deuteranomalopic subject (P. R.), the order of axes according to value of characteristic roots correpsonds to the order of axes for a trichromat, i.e., the root for the red-green axis has the highest value, then comes the one for the blue-green axis and the lowest for the white-black axis, but there is a greater difference between the roots of the first and second spatial axes, and particularly between the second and third. In the deuteranomalope P. R., the third (white-black) axis is negligibly greater than the fourth spatial axis, which we interpret as the result of experimental interference ["noise"]. This means that the color color discrimination space of a deuteranomalope is "flatter," i.e., it is close to an Euclidean plane. The findings are quite different for the protanomalope (subject S. A.). In this case, the blue-yellow axis is the most significant; the characteristic root of this axis is highest in value and differs drastically from the other roots. Next is the root of the white-black axis, while the characteristic root of the third, red-green axis is lowest in value. In subject S. A., the increased significance of the white-black axis signifies in spatial terms an even greater deviation from Euclidean space than in the case of the normal subject. In the following, we shall discuss the interpretation of these differences in terms of a spherical model of color discrimination, where we shall discuss the obtained data.

2. Spherical nature of subjective space: The spherical nature of the configuration of points obtained by means of multidimensional scaling is confirmed by the fact that one can always find a geometric center for a specified configuration of points, i.e., a point that is equidistant from all existing points. There must remain a high degree of correlation between the base estimates of differences and interpoint distances. The distance from the center of the sphere to each point may fluctuate due to judgment errors made by the subject. For this reason, in practice one must find a point as the sphere center for which the scatter of these distances (radii) is minimal. An interative procedure is used for the search, and it minimizes the standard deviation of radii from the central radius which are calculated at each step. One takes the center of gravity of the initial configuration of points as the starting point. After finding the optimum center in this sense, the entire configuration of points is shifted linearly so that the center of the sphere coincides with the start of the coordinate axes. The scatter of radii is measured by variability, as a percentage, of ratio of standard deviation to mean radius.

The results of the calculations are listed in the table of Euclidean coordinates obtained for each matrix of differences (Tables 4b-6b). At the end of each table, the values are given for the coefficients of correlation of interpoint distances and base differences with the variability of sphere radius obtained for a given configuration of points.

Table 3. Characteristic roots obtained for the analyzed matrices of differences

Axis No	Mean for 15 subjects	Mean for protanomalopes	Mean for deuteranomalopes	Subject P.R. (left)	Subject P.R. (right)	Subject P.R. (binoc.)	Subject S.A. (L)	Subject S.A. (R)	Subject S.A. (B)	Subject M.V. (L)	Subject M.V. (R)	Subject M.V. (B)
1	7092	14 763	10 307	11 793	5481	8781	15 602	14 959	13 997	6913	7330	7279
2	5322	22 934	5708	6043	5206	5553	3217	3592	3701	5237	4989	5609
3	1687	1790	803	1306	1990	1516	1532	1529	2690	1745	2239	2351
4	940	777	524	597	1207	1422	992	1230	1179	1224	800	955
5	488	650	278	341	987	896	652	811	614	816	618	570
6	296	323	150	136	673	506	244	482	386	476	540	201
7	137	171	25	31	530	0	166	70	65	299	247	110
8	55	0	0	0	156	0	0	0	0	0	71	0
9	0	—41	—37	—44	0	—22	—173	—74	—150	—44	0	—40
10	—164	—170	—266	—190	—44	—375	—254	—306	—280	—83	—213	—233
11	—202	—343	—444	—649	—489	—840	—364	—651	—612	—390	—460	—641
12	—202	—576	—576	—985	—618	—1041	—466	—1032	—885	—592	—687	—654
13	—469	—832	—1140	—1486	—1218	—1489	—1164	—1275	—1194	—750	—863	—829

Table 4a. Matrix of subjective differences (mean for 15 subjects)

Color	№	1	2	3	4	5	6	7	8	9	10	11	12	13
Blue	1		11	42	60	60	61	68	73	76	57	47	82	62
Light blue	2			34	58	60	57	61	72	75	56	50	50	55
Blue-green	3				36	41	42	50	60	66	56	47	49	33
Green	4					18	29	55	68	68	67	63	68	46
Green-yellow	5						19	54	63	69	67	60	62	43
Yellow-green	6							37	52	56	54	51	58	29
Yellow	7								24	32	43	44	44	36
Orange	8									8	45	45	48	53
Red	9										43	49	44	53
Purple-red	10											22	12	48
Purple-blue	11												7	33
Purple	12													44
White	13													

Table 4b. Coordinates of color points in Euclidean space (mean for 15 subjects)

Color	№	X_1	X_2	X_3	R
Blue	1	14,6	37,5	10,9	41,7
Light blue	2	15,2	34,0	12,2	39,5
Blue-green	3	19,6	11,6	32,7	39,9
Green	4	32,7	—14,5	29,1	46,1
Green-yellow	5	29,1	—14,5	33,8	46,9
Yellow-green	6	15,2	—16,7	35,6	42,2
Yellow	7	—16,1	—14,0	32,6	38,9
Orange	8	—30,8	—15,6	23,4	41,7
Red	9	—35,1	—16,8	21,6	44,5
Purple-red	10	—26,1	16,8	32,2	44,8
Purple-blue	11	—17,1	20,2	35,3	44,1
Purple	12	—22,7	21,7	32,9	45,5
White	13	1,8	1,3	44,4	44,5
Mean radius					43,1
Standard deviation					2,6
Variance					6,1
Coefficient of correlation					0,983

A comparison of these figures to one another indicates that the indices of sphericity are very similar to one another in all of the subjects. Variability of the radius ranges from 4 to 11%, with a coefficient of correlation of 0.96-0.98. This is quite consistent with the data obtained in [3, 5], and it indicates that one can compare not only subjects with normal color vision to one another, but also subjects with anomalous color vision in terms of a spherical model of color discrimination.

Table 5a. Matrix of subjective differences (subject P.R., mean for monocular and binocular presentations)

Color	№	1	2	3	4	5	6	7	8	9	10	11	12	13
Blue	1		0	19	64	64	58	77	84	87	41	32	37	36
Light blue	2			17	65	57	53	76	83	82	42	35	36	30
Blue-green	3				31	34	34	57	67	83	38	33	31	14
Green	4					1	11	71	84	85	67	55	62	40
Green-yellow	5						6	61	77	79	64	53	58	36
Yellow-green	6							35	51	58	44	43	47	28
Yellow	7								1	9	40	46	47	44
Orange	8									1	33	54	50	63
Red	9										41	57	48	59
Purple-red	10											6	2	25
Purple-blue	11												0	19
Purple	12													28
White	13													

Table 5b. Coordinates of color points in Euclidean space (subject P. R., mean for monocular and binocular presentations)

Color	№	X_1	X_2	X_3	R
Blue	1	−11,8	−41,8	64,1	77,5
Light blue	2	−12,5	−37,1	70,8	80,9
Blue-green	3	−19,8	−14,7	72,9	77,0
Green	4	−41,7	17,5	61,7	68,7
Green-yellow	5	−33,0	16,8	55,3	66,6
Yellow-green	6	−12,3	19,1	57,1	61,4
Yellow	7	28,3	24,1	56,3	67,7
Orange	8	43,2	20,3	48,1	67,7
Red	9	46,1	20,4	43,9	66,9
Purple-red	10	22,3	−13,9	65,7	70,7
Purple-blue	11	7,3	−16,8	59,7	62,4
Purple	12	13,6	−17,9	59,5	63,6
White	13	−5,3	−6,1	81,4	81,8
Mean radius					70,2
Standard deviation					6,9
Variability, %					9,8
Coefficient of correlation					0,982

3. Rotation of subjective space: The system of Cartesian coordinates in three-dimensional Euclidean space, which we obtained by the method of multidimensional scaling and in which we pursued our analysis to this point, is in no way related to the obtianed configuration of points, since all calculations up to now were made in terms of distances, which are unrelated to the selected system of coordinates in Euclidean space. In the spherical model of color discrimination, each Cartesian axis is interpreted as one of the same opponent characteristics of color, and it must be related to the color points by means of a certain form of

function; for this reason, of the many possible systems of coordinates we must choose the one that conforms with this interpretation.

Table 6a. Matrix of subjective differences (subject S. A., mean for monocular and binocular presentations)

Color	№	1	2	3	4	5	6	7	8	9	10	11	12	13
Blue	1		11	61	79	81	87	85	84	87	37	27	30	65
Light blue	2			58	72	79	80	83	80	82	45	29	27	60
Blue-green	3				60	59	57	63	65	66	38	47	42	10
Green	4					11	16	20	29	33	70	81	78	56
Green-yellow	5						9	9	23	25	65	77	68	54
Yellow-green	6							4	9	18	66	76	68	48
Yellow	7								7	13	68	68	70	53
Orange	8									9	66	72	77	61
Red	9										61	73	74	58
Red-purple	10											27	25	40
Blue-purple	11												11	51
Purple	12													53
White	13													

Table 6b. Coordinates of color points in Euclidean space (subject S. A., mean for monocular and binocular presentations)

Color	№	X_1	X_2	X_3	R
Blue	1	1,2	44,1	3,3	44,3
Light blue	2	8,1	39,1	2,4	40,0
Blue-green	3	10,7	11,4	40,8	43,7
Green	4	17,5	—35,7	8,8	40,7
Green-yellow	5	2,2	—35,4	17,5	39,6
Yellow-green	6	—1,7	—40,4	23,9	45,1
Yellow	7	—11,3	—37,3	21,0	44,3
Orange	8	—12,6	—37,5	16,0	42,7
Red	9	—17,5	—37,4	21,1	46,3
Purple-red	10	—13,2	24,0	28,0	39,1
Purple-blue	11	—11,6	39,6	20,3	46,0
Purple	12	—10,9	33,7	20,8	41,1
White	13	9,5	3,4	40,6	41,8
Mean radius					42,7
Standard deviation					2,5
Variability, %					5,8
Coefficient of correlation					0,982

In order to solve this problem, each configuration of color points is rotated orthogonally so as to meet the following conditions:

1) A positive direction of the X_1 axis characterizes the green phase of red-green opponent function; the maximum of this phase is in the color range with a wavelength of 505 nm [13, 14]; consequently, in our case, the X_1 axis must pass between blue-green and green (495 and 520 nm, respectively). A negative direction of the same axis corresponds to red or purple-crimson, according to Hartridge [9], phase, and for this reason must correspond to the position between purple-red and red (620 nm).

2) A positive direction of the X_2 axis analogously characterizes the yellow phase of blue-yellow function, which has a maximum in the color range with a wavelength of 575 nm [11]; consequently, this axis must, for the colors we took, pass between yellow-green (560 nm). A negative direction of the X_2 axis must, accordingly, pass between the points representing purple-blue and blue (480 nm).

3) The color points with maximum value (in positive or negative direction) for the first axis must have a minimum value for the second axis of coordinates and vice versa. This condition is applicable only to colors with about the same saturation; in our case, these are blue, green and red.

4) Use of white among the stimuli makes it possible to add one more condition: the point for white must have a maximum value for the third axis of coordinates and minimum value for the first two axes, since a positive direction of the X_3 axis characterizes the white phase of white-black opponent function.

These conditions are valid for subjects with trichromatic color vision. In the case of dichromatism, either the first or second condition is eliminated depending on the type of dichromatism.

These conditions determine unequivocally the only system of coordinates for each configuration of points. The values of these coordinates are listed in Tables 4b-6b. They characterize the opponent systems separately for each subject.

4. Standardizing the chromatic sphere: The nonzero variability of radii of the color sphere, which in our opinion is a consequence of errors in the subjects' appraisals, leads to the fact that, in each instance, the color sphere has a certain "thickness" in a radial direction, which makes it difficult to measure color functions. Moreover, the mean radius of the sphere fluctuates from subject to subject also, and this makes interindividual comparison difficult. We are not discussing here the intrinsic interpretation of radius of the color sphere, and in order to eliminate fluctuation thereof, we standardized the color sphere and thus transformed it into a unique [single] one: $X_{1i}^2 + X_{2i}^2 + X_{3i}^2 = 1$, where $X_{ir} = X_{ir}/R_i$, $i = 1, 2, \ldots, 13$; $r = 1, 2, 3$ and R_i is the radius of the ith point.

Standardization of the color sphere results in some shift of the color points in relation to one another, i.e., some change in interpoint distances. In order to assess this shift, we again calculated the coefficient of correlation between the base matrix of interstimulus differences and interpoint distances on the single sphere. They are listed in Table 7. A comparison of these data to the coefficients of correlation before standardization shows that the changes were very negligible, within the range of 0.01-0.02. This confirms the hypothesis of random fluctuation of the radius of the color sphere.

Table 7. Coefficients of correlation between matrices of initial differences and distances between points on single sphere

Matrix of initial differences		Configuration on single sphere: left eye	right eye	binocular
Subject M. V.	(left)	0,954	0,921	0,912
	(right)	0,921	0,959	0,896
	(binocular)	0,932	0,915	0,950
Subject P. R.	(left)	0,970	0,957	0,954
	(right)	0,964	0,971	0,953
	(binoc.)	0,948	0,950	0,963
Subject S. A.	(left)	0,972	0,941	0,939
	(right)	0,956	0,969	0,927
	(binoc.)	0,923	0,918	0,969
		Configuration on sphere		
Mean for 15 subjects (trichromats)			0,978	
Mean for 3 matrices (subj. P.R.)			0,972	
Mean for 3 matrices (subj. S.A.)			0,980	

After standardization, the construction of the spherical model of color discrimination is considered completed. All subsequent calculations and graphs based on them were made for the standardized and single coordinates of color points.

Results of Experiments

We have submitted our results in three different forms that reflect the successive stages of the diagnostic procedure.

As we have already indicated, the primary material, i.e., evaluation of paired differences between color stimuli, is submitted in the form of triangular matrices of differences in Tables 4a-6a. Table 4 lists data that were averaged for 15 matrices. They refer to both monocular and binocular evaluations, but all of the data were obtained on subjects with normal color vision. This did not include the data for subject M. V., which are listed by us as an example of a normal trichromat. Table 5a lists data for the deuteranomalopic subject, P. R., averaged for three matrices, while Table 6a analogously lists data for protanomalopic subject S. A., averaged for three tests.

Tables 4b-6b list the results of multidimensional scaling of each of these matrices of differences. In all of the tables, the colors used have the same names and numbers as in Table 2. The Euclidean coordinates of each point after rotation of space and shift of the sphere to the start of the coordinate axes are listed in columns X_1-X_3 in Tables 4b-6b. At the end of each table, the coefficient of correlation between initial evaluation of differences and Euclidean interpoint distances is given.

The constant distance between each point to the center (radius) is proof of the sphericity of the obtained configuration of points. The values of the radii are listed in Tables 4b-6b, in column R. Below are the values of the mean radius for all points of standard deviation from the mean, and variability, the value of which characterizes the relative scatter of radii as a percentage of the mean.

These data define the subjective color space, regardless of the spherical model of color discrimination.

The final answer, in terms of the spherical model, are given in the form of drawings of spherical diagrams of chromatism and opponent functions. These data are sufficient to illustrate the potential of the proposed method of evaluating color vision.

Diagnostic Analysis of Data

Comparison of results to data for monochromatic colors: Unlike monochromatic stimuli, which are traditionally used to plot chromatic functions, the color stimuli we used here to evaluate color vision have a complex spectral composition, as a result of which they have less saturation than monochromatic colors; they are characterized by wavelength, like monochromatic colors, with regard to color tone (Table 2).

Evaluation of color vision for this group of subjects in terms of a spherical model can be based only on a comparative analysis of configurations obtained in one test. It is of no significance here whether the stimuli have a complex spectral composition or simple, monochromatic one. But in order to be able to compare data obtained at different times, with the use of different sets of stimuli, it makes sense to relate specific configurations of color points to the configuration of monochromatic colors in each instance. This would make it possible to distinguish between changes caused by specific sets of stimuli from those obtained due to the distinctions of color discrimination.

Such a comparison is drawn in Figure 4. The projection of the sphere on plane X_1X_2 is illustrated in Figure 4a. The thin solid line shows the trajectory of monochromatic colors on the surface of the sphere, plotted from the mean data for normal color discrimination. The trajectory ends arbitrarily in the region of purple colors with a geodesic line that passes through the points for blue and red (440 and 660 nm, respectively). The wavelengths of the colors are shown near some of the points. The interval between points is 10 nm. On the same graph, the configuration of points representing the colors used in this study is shown by the large dots connected by heavy lines. These data were also obtained from averaging those referable to the 15 subjects with normal color vision.

Quite obviously, the configuration of nonspectral colors is "inscribed" in the configuration of spectral ones, which is the consequence of lower saturation of nonspectral colors. Blue, green, yellow-green, green-yellow, yellow, orange and red are closed to the spectral colors. One can assess the accuracy of calorimetric measurements in terms of the chromatic MOK-31 diagram according to the position of these colors in relation to the spectral line. In general, all of the wavelengths calculated calorimetrically and listed in Table 2 correspond to the wavelengths of the points that represent these colors on the sphere. Yellow is an exception; according to calorimetry it has a wavelength of 585 nm, but it is located on the sphere in the region that is characterized by a wavelength of ~595 nm, according to its spectrum.

Now the configuration of nonspectral colors on the sphere serves as a sort of standard, according to which we evaluate the subjects' individual data. The graphs of red-green, blue-yellow and white-black functions, plotted for nonspectral colors according to the averaged data for 15 subjects with normal color vision, which are illustrated in Figure 4b, are an analogous standard for plotting opponent color functions. The wavelength of the color is plotted on the x-axis and the value of coordinates X_1 (red-green function), X_2 (blue-yellow function) and X_3 (white-black function) are plotted on the y-axis. They are compared to the data for monochromatic colors, in the same way as in Figure 4a. These opponent functions are not plotted for all colors, but only those which, as shown in Figure 4a, are closest to spectral. This was done so that the opponent functions that we obtained for nonspectral colors would retain the customary form of traditional spectral opponent functions. The discrepancies we see in Figure 4b are the result of differences in sets of stimuli, analogously to what we discussed, rather than discrepancies of color discrimination.*

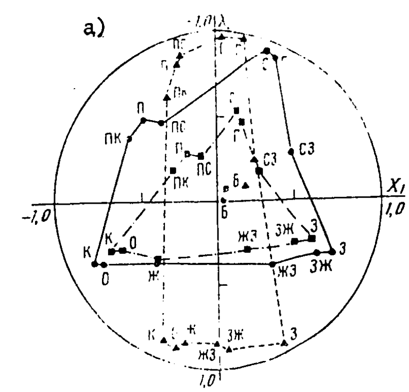
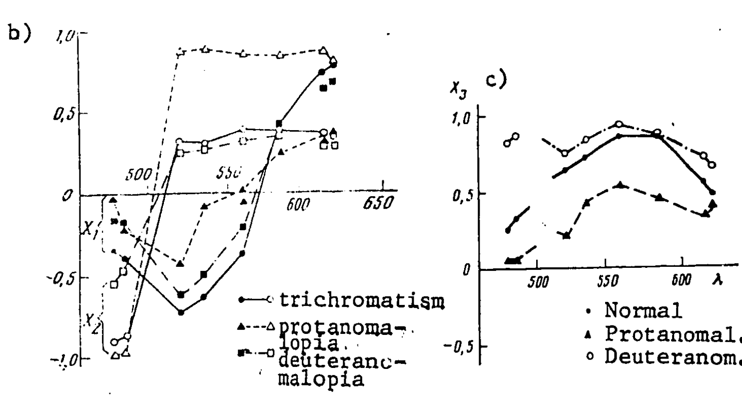


Figure 4.
Spherical model of color discrimination for normal trichromatic, protanomalopic and deuteranomalopic vision

a) spherical diagram of chromatism. The circles connected by a solid line represent the configuration of colors for normal vision; triangles connected by a dash line represent configuration for protanomalopic vision and the squares connected by dash-dot lines deuteranomalopic vision
b) ɔpponent functions calculated in accordance with data for normal, protanomalopic and deuteranomalopic vision; black symbols refer to red-green functions X_1, white to blue-yellow X_2
c) white-black ɔpponent functions for the same forms ɔf color vision (designations of forms of color vision are identical in all three figures)



Key for this and Figures 5a, 6a and 7a:

П) purple
ПС) purple-blue
ПК) purple-red
С) blue
Г) light blue
СЗ) blue-green
Б) white
ЖЗ) yellow-green
ЗЖ) green-yellow
О) orange
Ж) yellow
К) red
З) green

*Translator's note: In the source, reference is made throughout this section to Fig. 3; however, it appears it should be Figure 4.

Of special interest are the curves illustrated in Figure 4c for white-black opponent function, which characterizes the whiteness of equally bright colors in the spherical model. In general, this function coincides with the analogous one obtained for spectral colors; but since colors with wavelengths in the range of 490-510 nm, where white-black function has an additional peak, are not represented among the non-spectral stimuli, the graph of white-black function shows a break in this place. In some cases, when it is necessary to describe the behavior of colors in this range, we shall draw upon additional data for blue-green (495 nm); but it must be borne in mind that it is significantly shifted itself from the trajectory of spectral colors (Figure 4a) in the direction of white.

Evaluation of Color Vision According to Averaged Data

The traditional methods of evaluating color vision, which we discussed above, perform classification chiefly according to forms of color vision as, for example, shown in Table 1. In this section, we shall discuss how an analogous classification is made in terms of the spherical model of color discrimination. For this analysis we took the average data separately for each of the subjects representing three different forms of color vision. Averaging was done for three matrices of base differences: binocular, monocular for the left and right eyes. Each of these matrices is known to characterize the same form of color vision, since they were obtained for the same subject. And each subject is characterized only by one form of color vision for both eyes, as can be seen in Table 1. For this reason, averaging should only emphasize the typical characteristics of each form as a result of leveling off individual differences within each form.

Table 5a (deuteranomalopia) and Table 6a (protanomalopia) list the averaged matrices of differences for anomalous forms. As an example of normal color vision, we used the data discussed above referable to 15 subjects (Table 5a). The results of multidimensional scaling of these matrices are listed in Tables 4b, 5b and 6b, respectively. There too, the characteristics of sphericity of the obtained configurations are given: variability of radii and coefficient of correlation for distances between points in relation to initial differences.

The spherical color diagram (Figure 4a) serves as the principal material for evaluation; it illustrates the configuration of color points characterizing each form of color vision. The points connected by solid lines show the configuration for normal color vision; squares connected by a dash-dot line illustrate deuteranomalopic vision, while the triangles connected by a dash line represent protanomalopic vision. The differences between forms of configurations are very substantial, and they can be used for error-free determination that we are dealing with deviations from normal color vision. A comparison to the standard configuration of normal color discrimination shows that in deuteranomalopic subject P. R. there is approximation of points in relation to the red-green X_1 axis, which is particularly significant in the blue-purple part of the diagram. Approximation of color points in terms of the spherical model indicates worsening of sensitivity to color discrimination. As compared to normal color discrimination, there is poor differentiation here between blue-green and white; all three purple colors are also poorly distinguished from white. The entire series of colors, from red to green, is differentiated worse than with normal color discrimination. However, discrimination is less reduced in the long-wave part of the spectrum than the short-wave one. In addition to changes in color discrimination on the red-green axis of the spherical diagram, the deuteranomalope presented compression of color configuration on the blue-yellow X_2 axis also, and it affects chiefly blue. This may be a feature only of this subject, P. R.; however, it is more likely that this is a manifestation of a distinctive feature of deuteranomalopia in general, as also indicated by comparing these changes to those characterizing protanomalopic vision. As seen in Figure 4a, the color configuration is also deformed in two directions, red-green and blue-yellow with protanomalopic vision. But while there is compression in the red-green direction, as in the deuteranomalope, the changes are different in the blue-yellow direction; they affect chiefly yellows, rather than blues, and the colors are shifted away from white, rather than to it. These opposite tendencies of changes referable to the blue-yellow axis of the spherical diagram in the deuteranomalope and protanomalope can be interpreted as additional classification tags for different forms of color vision.

The general findings referable to deuteranomalopic vision are indicative of the systematic shifts of color points from the periphery of the spherical diagram toward its center, toward the point for white. The changes are generally different in the protanomalope. Here we can readily distinguish two small regions of space, in which virtually all colors are grouped: purple and blue-light blue in the blue zone, orange-red and yellow-green in the yellow zone. These zones are localized along the blue-yellow axis of the space on different sides of white. It may be assumed that the pole of the sphere represents another, third zone, in which purple-crimson and blue-green should be located. This is confirmed by the fusion of white and blue-green, which is seen on the diagram.

The difference between deuteranomalopic and protanomalopic vision shows that the traditional problem of considering anomalous forms as merely quantitative deviations from normal color vision is solved differntly here. For the deuteranomalopic subject this hypothesis coincides with the general changes in subjective space of color discrimination, and for the protanomalopic subject it is not confirmed, although this conclusion, of course, requires considerable statistics for each form.

As we have already stated, in addition to a general description of color vision in terms of the spherical model, one can also make comparisons of various special characteristics. To illustrate this thesis, we shall compare different forms of color vision according to color opponency functions [Figure 4b and c). From the standpoint of opponent colors theory, the change related to each type of anomaly should be manifested by specific changes in opponent functions. Deuteranomalopia leads to reduction of red-green function and a shift of the point of intersection of blue-yellow function and the zero x-axis in the direction of the long-wave end of the spectrum, while protanomalopia leads to reduction of red-green function and a shift of the point of intersection of the second function and zero axis in the short-wave direction. The degree of change is related to the degree of anomalousness of color vision. In the case tritanopia and tetartanopia, the reduction is referable to blue-yellow function, while red-green is retained.

A comparison of opponent functions of anomalous and normal forms of color vision plotted within the framework of the spherical model generally conforms with the theses of opponent theory. For both the protanomalope and deuteranomalope, the red-green function is reduced, as compared to normal vision. In the protanomalopic subject, this reduction of red-green function is more marked, and this characterizes his greater anomalousness, as compared to the deuteranomalopic subject. In most cases, it is impossible to make such comparison between different forms by the traditional anomaloscopic methods, since the coefficients of anomalousness of the deuteranomalope and protanomalope are parameters on two unrelated ordinal scales. The change in blue-yellow function differs somewhat from the theoretically assumed one. Since colors in the range of 480-510 nm are not represented here, the presence or absence of a shift of the point of intersection of the functions with the zero axis cannot be determined, particularly for the deuteranomalope, although by extrapolation the shift in the short-wave direction is very obvious in the protanomalope. At the same time, there is also a significant change in opponent function: it increases in the yellow phase in the protanomalope and decreases in the blue phase in the deuteranomalope.

Considerable changes can also be demonstrated in the form of white-black function, and each phase of color vision affects this function in its own way (Figure 4c). With deuteranomalopic vision, the value of the short-wave part of the function grows appreciably, whereas with protanomalopic vision it decreases in the range of average waves. The general difference between anomalous and normal vision is manifested by a drastic increase in values of the function in the local 490-510 nm segment. One cannot demonstrate this change in overt form, because the blue-green color used in this study is poorly saturated, as compared to other colors (Figure 4a). However, one can assess this local change indirectly, even on this poorly saturated color, and for this reason its position is indicated in Figure 4c separately from white-black function by the white symbols. The symbols correspond to the black symbols of color vision (circles--normal, triangles--protanomalopic and squares--deuteranomalopic vision).

Thus, the combination of general features of color discrimination (in the form of configuration of color points on the spherical diagram) and special features (in the form of opponent functions) makes it possible to unequivocally differentiate between forms of color vision. In this case, evaluation can be made both visually, according to the overall configurations, and formally, using the amplitudes of each phase of opponent functions as indicators. As we have already seen, the results of our evaluations are completely analogous to the results of the most refined of the procedures used in practice, i.e., anomaloscopy. In the next section we shall discuss evaluation of color vision within each form, and we shall demonstrate that they are readily demonstrable, even upon visual analysis of configurations of color points on the spherical diagram.

Comparison of Individual Characteristics of Color Vision

Formal description of individual spherical diagrams. Before we discuss the meaningful aspect of individual differences, we shall briefly analyze the extent to which different configurations of points on a single sphere differ on the basis of a formal solution, when the obtained data merely represent a certain geometric shape. Since the configuration of points is formally given to us as the distance between points, the subject of our analysis will be the matrice of distances between pairs of points. The problem is to check the extent to which the interpoint distances for a given configuration are closer to their base matrix of differences han they are to some "alien" matrix. The coefficient of linear correlation serves as the gage of closeness. And we compare only data, for which the probability of confusion of configurations is particularly high (such as data for the left and right eye of the same subject, monocular and binocular presentation, etc.), since the differences between a normal and anomalous subject are already quite obvious from the base data. Table 7 lists the coefficients of correlation, which were calculated to compare each configuration to each base matrix of differences. The calculations indicate that, in all cases, "its own" matrix is better correlated with the obtained configuration than a "foreign" one.

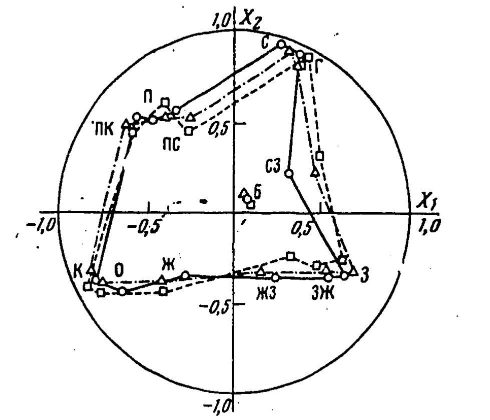
Normal trichromatism: Let us discuss the spherical chromatic diagram illustrated in Figure 5a, where configurations are shown that were plotted from the data referable to subject M. V. The triangles connected by a dash line refer to the right eye, while the white circles connected by a thin solid line refer to binocular color discrimination. Data for the averaged matrix (boldface points connected with boldface line) are given against the background of the individual graphs.

A comparison of individual data to one another and with the averages shows that there is no systematic difference between them. Both the left and right eye of subject M. V. have generally the same spherical diagrams, that are very close to the averaged data. Since both eyes of subject M. V. present the same color discrimination, binocular color discrimination is also in the range of the averaged standard diagram, as we had assumed. It must be noted that, as can be seen on the spherical diagram, this subject is characterized by rather wide scatter, as compared to averaged data, i.e., considerable experimental "noise." This can also be seen from the magnitude of variability of scatter of radii and coefficient of correlation between the answer and base evaluations. While variability constitutes 6.1% for the mean data, with 0.983 coefficient of correlation, in subject M. V., who presents less correlation (0.963 binocularly, 0.960 right eye and 0.959 left eye), variability is greater (11.1 binocular, 4.4 right eye, 7.8 left eye). The principal cause of this noise is the sm..l amount of statistics: each element of the matrix of differences for subject M. V. i. the mean of only 10 ratings, while the averaged matrix of differences is given for 150 ratings. Moreover, this subject is characterized as one of the "noisiest," even in comparison to others for whom there is also a small amount of statistics (or even less). The chief reason for including expressly his data, instead of a better subject, is that M. V. was tested in the same group of subjects with anomalous color vision that represent the main data in our experiment. According to the findings on subject M. V., which are illustrated in Figure 5a, he can be unequivocally characterized as having normal color discrimination in both the left and right eye.

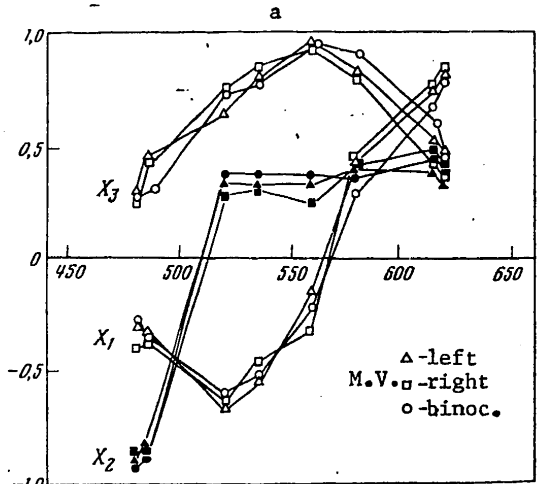
Th.s is evident just as clearly on the graphs of three opponent functions illustr.ted in Figure 5b: red-green X_1, blue-yellow X_2 and white-black X_3. The triangles, squares and circles refer to data for the left and right eye, and binocular vision, respectively.

No changes were demonstrable that could be related to some anomaly of color vision on the curves illustrated in Figure 5b. They coincide entirely with the curves that characterize our standard for normal color discrimination (Figure 4b). Thus, according to the results illustrated in Figure a and b, subject M. V. is characterized as a normal trichromat. This diagnosis conforms entirely with the results of both anomaloscopy and evaluation with the polychromatic tabl...

Deuteranomalopia: Very different color discrimination was found in subject P. R. Figure 6a illustrates the spherical diagram with configurations characterizing the color discrimination space for the left and right eyes, and binocular vision (see key for Figure 5a). The position of the color points, like for the averaged data,



a



b

Figure 5.
Spherical color diagram (a) and opponent functions (b) for subject M. V. The circles refer to data for binocular vision, triangles for left eye and squares for right eye in (b) [also see key for Figure 4]

indicates a consistent deviation from the configuration characterizing normal color discrimination in the direction of white, i.e., there appears to be reduction of color saturation. However, the magnitude of the shift is not the same for the left and right eye: for virtually all colors, the right eye presents poorer color discrimination than the left. The configuration for binocular vision is in an intermediate position, between monocular, which is indicative of equal participation of each eye in binocular vision, i.e., conformity with the simplest (though, of course, not the only possible) form of binocular interaction.

If we analyze the functions of this subject (Figure 6b and c), it is also easy to see that the right eye (squares) presents more change than the left, whereas in binocular color discrimination the function occupies an intermediate position between the left and right eye. The change in red-green function affects mostly the green phase, and to a lesser extent the red; but we cannot state this with complete certainty, since the red phase of this function is only partially represented. There are corresponding changes in blue-yellow function of subject P. R. The yellow phase of the function remaining unchanged, there is distinct reduction of the blue phase; this reduction is more marked for the right eye than the left. These changes indicate that subject P. R. is characterized, as is usually the case, by a mixed form of anomaly, deuteranomalopia with some worsening of the short-wave mechanism also, rather than a pure form of anomaly (from the standpoint of opponent theory). The white-black function for subject P. R. is illustrated in Figure 6c. Under all observation conditions, it differs from normal white-black function in that there is a very marked elevation in the short-wave region of the spectrum. The white-black function of the deuteranomalopic subject is virtually the same as in normal vision in the long- and short-wave regions of the spectrum. This confirms the thesis that a change in the short-wave region of the spectrum can serve as a distinctive feature of deuteranomalopia, in addition to the main features manifested by changes in red-green function.

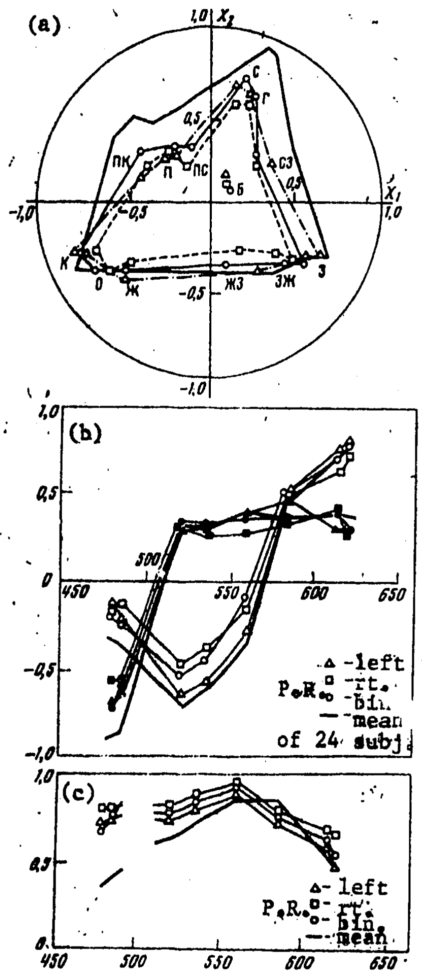


Figure 6.
Spherical color diagrams (a) and opponent functions (b, c) for subject P. R.

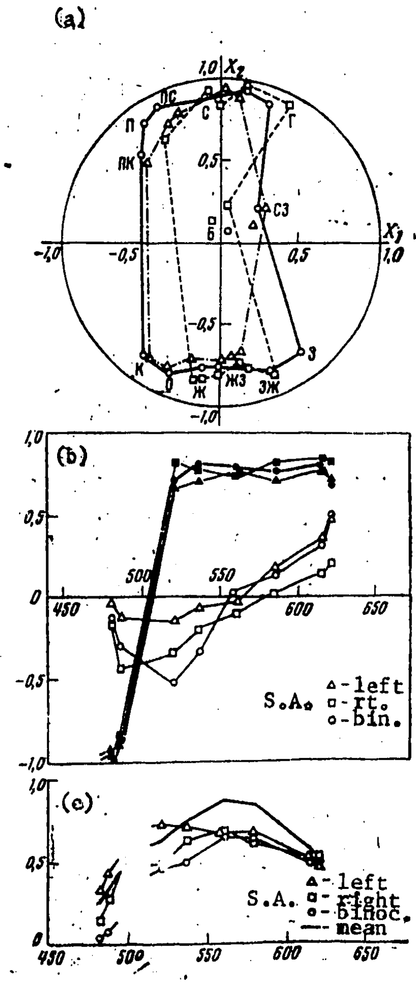


Figure 7.
Spherical color diagrams (a) and opponent functions (b, c) for subject S. A.

(For both above figures, see key to Figure 4 and caption to Figure 5)

The results obtained conform entirely with the evaluation made in Table 1 for this subject; the difference between the right and left eye, diagnosed only by means of anomaloscopy, is also very distinctly manifested as a result of using our diagnostic method. The right eye of subject P. R., which has a higher coefficient of anomalousness, is characterized by greater anomaly in terms of the spherical model of color discrimination as well. Moreover, the method we propose permits evaluation of binocular color discrimination also, and as we have seen from the data submitted for subject P. R., the latter does not necessarily coincide with either the left or right eye; of course, one could have assumed the binocular characteristics as well on the basis of monocular evaluations, but it is easy to predict the variant of monocular differences when it alone cannot be used for even an approximate evaluation of binocular vision (for example, when one eye is normal and the other is anomalous, etc.).

It must be noted that there was considerable less "noise" for the results we obtained on subject P. R. than the subject with normal color discrimination; while variability of sphere radii was the same, the coefficient of correlation to base evaluations was higher for the former.

Protanomalopia: The new variant of configurations obtained for subject S. A. is illustrated in Figure 7a (see the key to points on the spherical diagram in Figure 4). In the case of protanomalopia, the configuration of color points differs substantially from both the configuration of the normal subject and deuteranomalope. In subject S. A., the differences between configurations characterizing the right and left eye were even more significant than in subject P. R. The left eye of S. A. discriminates very poorly between green and yellow-green. We see on the graph that the points representing these colors have virtually coincided and they shifted toward the yellow half of the X_2 axis. At the same time, light blue and blue shifted toward the blue half of the X_2 axis. Orange-red colors are also shifted toward the yellow half of the X_2 axis, but they are distinguished from one another considerably better than yellow-green colors. The same can be said about purples, as compared to blue and light blue. The overall features of the color space for the left eye of subject S. A. are the same; for the averaged data for protanomalopic vision (Figure 4a), the color space is compressed on the first spatial axis, and all colors are grouped in three small loci situated along the second axis. The same tendency of marked separation of all colors into three loci is also inherent in the right protanomalopic eye of subject S. A. But while the left eye forms a configuration that is more compressed in the green half of the red-green axis and less so in the red half, the opposite is observed for the right eye: more compressed red half of the axis than the green, i.e., the red and green phases of this opponent system may change differently, depending on the individual distinctions of the color analyzer.

Subject S. A. differs from the others in bionocular color discrimination also; in subject P. R. it could be interpreted as average, intermediate between the two forms of monocular color discrimination, whereas in subject S. A. binocular color discrimination constitutes a summary result, and the configuration of color points on the spherical diagram (Figure 7a) representing binocular color discrimination contains both monocular configurations.

The opponent functions for subject S. A. are illustrated in Figure 7b and c. The chromatic opponent functions (b) are drastically deformed, and in general this deformity is consistent with the predictions of opponent colors theory. However, there are also differences that are referable to one and the other opponent functions.

The red-green function (Figure 7a, white symbols) is reduced in both the red and green phase; however, the extent of this reduction in these phases is not proportionate. For the left eye there is more reduction of the green phase and for the right, the red phase of opponent function, as compared to normal vision. We had already partially observed this asymmetry in subject P. R., but for him the green phase presented more reduction than the red in both eyes. This asymmetry explains why evaluation of the forms of color vision--protanomalopia and deuteranomalopia--should not be made according to opponent function in general, but separately according to each of its phases. As shown by the data on subject P. R., in the case of deuteranomalopia there are more marked changes in the green phase of red-green function; they are correlated with the degree of anomalousness (i.e., reciprocals of the coefficient of anomalousness) as well as the general characteristic of color vision which, as we have already stated, is the region of color discrimination space on the chromatic diagram. For protanomalopic subject S. A., it is expressly the variability of the red phase of red-green function that is correlated to both a change in region of color discrimination space (its area is smaller for the right eye than the left) and degree of anomalousness (the anomaly coefficient is higher for the left eye than the right) (Table 1). The changes in the green phase with protanomalopia, like those in the red phase with deuteranomalopia, can be utilized for a more comprehensive analysis within each form of anomalous trichromatism. Under all observation conditions, the graph of blue-yellow opponent function varies significantly in the yellow phase and is constant in the blue for subject S. A. (Figure 7b, black symbols). This change is the opposite of what we observed in deuteranomalopic subject P. R. (Figure 6b), where only the blue phase varies. At the same time, from the change in this opponent function there is nothing we can say about differences within each form, protanomalopia or deuteranomalopia, since blue-yellow opponent function is the same for both eyes, in spite of the appreciable differences between the left and right eye of subject S. A. (as was the case for subject P. R.).

In the protanomalopic subject, the white-black function diminishes in the yellow-orange region, and this decline is generally unrelated to the eye that the subject uses. This distinguishes the white-black function of a protanomalope from that of a deuteranomalope, where the change affects mainly the short-wave part of the spectrum. As in the case of deuteranomalopia, we submitted the break in this function in the range of 490-510 nm, since we cannot overtly demonstrate a significant rise of the peak, which is distinctly visible in the white-black function of monochromatic colors (Figure 2b).

Analysis of configuration of color points on the spherical diagram and opponent functions of protanomalopic subject S. A. shows that diagnosis of this form of anomalous color vision in terms of the spherical model of color discrimination coincides with the results of analysis that we established by traditional methods. At the same time, it is apparent that the spherical model of color discrimination permits finer differentiation between the color vision of this subject and others. The advantages of the spherical model are even more evident when we examine the individual characteristics within this form of color vision, as we see from the data of comparing monocular and binocular color discrimination.

The minimal "noise" in the results of subject S. P., as compared to others, serves as confirmation of the reliability of qualitative analysis of his data. With variability of radii of 7-10%, the coefficient of correlation with initial evaluations reaches a maximum for values of 0.97-0.98.

Conclusions

1. A spherical model of color discrimination is proposed, according to which the entire set of equally bright colors can be designated with points on the surface of

a sphere in three-dimensional space, with the color white on the pole and spectral colors nearing the planes of the equator to different degrees.

2. The entire psychological diversity of colors is defined by angles: horizontal that correspond to the color hue and vertical that correspond to saturation. The physiological characteristics of color discrimination are three orthogonal systems of coordinates representing the red-green, blue-yellow and white-black opponent systems of neurons.

3. The subjective difference between colors is measured with the small arc of a large circle drawn through the points representing colors on the sphere.

4. Knowing the matrix of subjective differences between colors, one can calculate the coordinates of points corresponding to colors in three-dimensional space on the surface of the sphere and obtain an individual diagram of color vision for a given subject.

5. The subjective diversity of colors in cases of protanomalopia and deuteranomalopia is also situated on the surface of the sphere in three-dimensional space; however, the configuration of the color diagram differs from normal.

6. A comparison of individual diagrams of color discrimination makes it possible to separate and describe quantitatively the different forms of color vision disturbances. The data obtained by the method of multidimensional scaling coincide with the evaluations made on the basis of anomaloscopy and polychromatic tables. However, the method of plotting individual diagrams of color vision permits more accurate differentiation between individual distinctions of color vision.

7. One can obtain individual diagrams of color discrimination simultaneously for an entire group of subjects by the method of automatic evaluation of color vision, which is based on a computer-controlled color television. The procedure of determining the properties of color vision is reduced to a simple system of evaluating subjective differences, while data about the properties of color discrimination are obtained with the use of a computer.

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OPTICAL METHODS OF TRANSFORMING VISUAL FEEDBACK

Moscow PSIKHOLOGICHESKIY ZHURNAL in Russian No 3, 1980 pp 85-94

[Article by V. A. Barabanshchikov, B. I. Belopol'skiy and N. Yu. Vergiles]

[Text] For the last few years, a wide circle of specialists has given its close attention to studies of quantitative and qualitative distinctions of eye movements. Among the numerous aspects of analysis of oculomotor activity, a special place belongs to the study of principles and mechanisms of function of the system that regulates eye movements under different observation conditions.

It must be noted that the existing conceptions of function of the human oculomotor system (OMS) are largely related to the choice of methodological research procedures. Thus, the use of several new experimental procedures--presentation of "pulsed," dual "pulsed" stimuli [14, 15], stimuli that are stabilized in relation to the retina [2, 5, 6]--yielded some new data on OMS function that do not always by far conform with the conventional conceptions.

Our objective here was to describe the "battery" of special methods of studying the OMS, which are based on the same principle: transformation of visual feedback.

Let us consider the main elements of the OMS. A signal of discrepancy between the position of the fixed object on the retina and center of the fovea is delivered to the input of the system. The output of the system is a turn of the eye. The purpose of regulation is to minimize the input signal. Thus, the system is established in a stable position only when the projection of the object of fixation on the retina coincides with the fovea. Since each turn of the eye in the direction of the object of fixation is associated with attenuation of the error [discrepancy] signal, the human OMS can be described (by analogy with technical systems of automatic regulation) as a tracking system of positional monitoring [control] with negative feedback [1, 8].

The fact that there is feedback in the OMS is of utmost methodological importance, since transformation of output-input relations opens up new avenues for analysis of the patterns of OMS function and its extrasystemic links. (Let us recall that a change in feedback is one of the principal investigative methods for technical systems of automatic regulation.)

We can distinguish three main parameters of transformation of visual feedback of the OMS: magnitude, sign and direction. The magnitude of visual feedback is the ratio of angle of eye movement to angular amplitude of displacement of the projection of the object of fixation over the retina. Under ordinary conditions of OMS function, one can consider the visual feedback to equal one. However, in principle this parameter may be either >1 (visual angle by which the projection of the object shifts is larger than the angle of eye movement) or <1 (opposite relation between angles). Stabilization of the image of an object in relation to the retina corresponds to the case when the magnitude of visual feedback equals zero.

The sign of visual feedback in the OMS system indicates the relative change in the input signal when the eye turns, and it may be negative (normal) or positive. In the latter case, when the eye turns the projection of the object of fixation on the retina should not approach the fovea, but move away from it in the diametrically opposite direction.

The quantitative sign and magnitude of visual feedback of the OMS can be expressed by means of the coefficient of visual feedback $\pm K_{fb}$.

The concept of a sign of visual feedback implies that the parameter of regulation is one-dimensional and, as applied to the OMS, narrow. Since regulation of eye position takes place in at least two coordinates, it is possible for the projection of the object on the retina to shift, in the most varied directions, in relation to the fovea. For this reason, in the general case, regulation of eye movements can be described in terms of direction of visual feedback in the OMS.

At the present time, we know of several experimental procedures that permit alteration of parameters of OMS visual feedback.

1. Anatomical-physiological disruption of oculomotor relations: a) surgical change in these relations; b) use of drugs to affect the muscular system of the eye; c) energy effect of light on the retina, which leads to appearance of an afterimage [2, 9, 11, 12, 17, 19]. These procedures are not always applicable to man, and the range of possible changes in K_{fb} is narrow (K_{fb} = 0; +1).

2. Use of external optical systems. When a strong diverging or converging lens is placed before the eye at a certain distance, perception of an entoptic image of the pupil can be obtained. The link between movement of the projection of the pupil over the retina and eye movements can be changed over a rather wide range, including a change in sign and value of K_{fb}, and one can also stabilize the image in relation to the retina (K_{fb} = 0) [7, 21]. One of the variants of this method is the use of a spherical mirror. In this case, the object of perception is a light spot formed as a result of reflection by the cornea of an external point light source. K_{fb} depends on the position of the center of eye rotation in relation to the focus of the mirror [10].

3. "Optical levers." The focused projector beam is reflected from a small mirror attached to the eye by means of suction cups or contact lens on a screen. By changing the range of the beam from the screen to the eye and its direction, one can change both the magnitude and sign of K_{fb} [8, 10].

4. Electronic control of position of stimulus. This method has become the most popular [16, 20]; it is based on the fact that an electronic signal that records eye movements is delivered to the input of a display. Amplification, inversion or other, more complex manipulation of the signal in the external circuit, between the eye movement recorder and display, make it possible to obtain the entire range of changes in K_{fb}, of interest to us, including the direction of feedback.

It must be noted that the described methods of transforming visual feedback of the OMS have a number of flaws and limitations.

In the first place, almost all of them impose rigid limitations on both the characteristics of test objects--their size, shape, content, spatial dynamics--and mode of action of subjects. In the second place, most of these methodological procedures have a narrow range of amplitudes of eye movements, for which the specified conditions of K_{fb} are retained. In the third place, some of the methods of altering OMS visual feedback do not rule out the possibility of having part of the equipment and furnishings, perceived without change in K_{fb}, within the field of vision. Finally, in the fourth place, these methods are rather labor-consuming, and they do not always assure the desired degree and accuracy of change in parameters of visual feedback.

Evidently, the most adequate method of altering visual feedback to study the OMS and mechanisms of visual perception should be one that would allow us to exhibit for a long time objects of any shape and congent, both stationary and moving, with strict monitoring of eye movements and K_{fb}, and without restricting the observer's own movements. The principle expounded here meets these requirements; it consists of transforming the projection relations of objects of perception on the retina by means of artifical optical devices attached directly to the eye. Let us note that special forms of this principle (change in sign of visual feedback, stabilization of image of objects in relation to the retina) had been worked on before [7, 13, 21], but were not submitted to proper development.

Optical Change in Magnitude of OMS Visual Feedback

This method is based on the effects that arise when the coefficient of magnification of the eye's optical system is changed. It consists essentially of the following.

The projection of a stimulus on the retina is defined by the angle between its position and the optical axis of the eye. It is expressly by this angle that the eye must turn for the stimulus to be projected in the middle of the fovea (Figure 1a). There are analogous relations when a magnifying or reducing optical system is before the eyes (for the sake of simplicity, Figure 1b shows only one positive lens). Then the stimulus is seen under angle α, i.e., it corresponds to the angle of vision of imaginary image $a''o''$; the eye most turn under the same angle α in order to provide for fixation of point a''.

When, however, the optical system turns together with the eye (Figure 1c), the angle of eye rotation needed for exact superposition of the projection of point over the foveal region equals β. From the plot we see that $\alpha \neq \beta$, with $\alpha > \beta$ when an enlarging lens is used and $\alpha < \beta$ when a reducing one is used.

Ratio α/β will give us the value of K_{fb}. It is not difficult to observe that the absolute value of α/β coincides with the coefficient of magnification of the optical system. Consequently, by altering the power of the optical system one can also control the value of K_{fb} without changing the natural sign (negative) of feedback.

In practice, this method was executed in the form of an optical system attached to a central suction eyecup. Each optical system consisted of two lenses, positive and negative, which provided for focusing of a sharp image on the retina. When using a negative lens as the ocular (Figure 2a), the system operated with magnification and with a positive lens as an ocular (Figure 2b), with reduction. The lens diameter ranged from 5 to 8 mm. The size of the visual field, 15-40°, depended on the coefficient of magnification of the optical system.

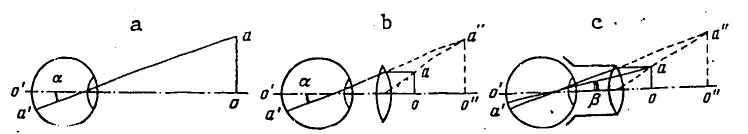

Figure 1. Drawing illustrating the angle of displacement of projection of an object over the retina as a function of angle of eye movement

a) under ordinary conditions
b) with lense in front of the eye
c) with lens attached to eye
o, *a*) objects of fixation
o', *a'*) projection of objects on retina
o'', *a''*) imaginary (perceived) position of objects in space
α, β) angle of eye movement from point *o* to *a*

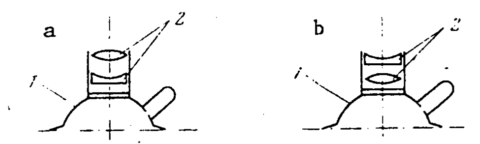

Figure 2.
Schematic illustration of suction eyecups with optical systems used for magnification (a) and reduction (b) of angle of projection of exogenous object on retina
1) housing of suction cup with central tube
2) optical system consisting of positive and negative lenses

Figure 3 illustrates typical tracings of eye movements with K_{fb}<-1 and >-1. We see that the fixation turn with K_{fb} >-1 consists of a series of unidirectional saccadic movements, the amplitude of which diminishes until the eye reaches a stable position. This mode of fixation turning can be designated as the mode of "underregulation." With K_{fb} <-1, the fixation turn is made in the "overregulation" mode, where the amplitude of saccadic movements exceeds the angle of turn required to reach the goal, while a stable eye position is achieved by means of a series of saccadic movements in different directions, with gradual extinction of oscillations. In both modes, the amplitude characteristics of the saccadic movements constituting the fixation turns and, accordingly, the number of saccadic movements in them are closely related to the value of K_{fb}.

Optical Change in Sign of OMS Visual Feedback

This method is based on inversion of the retinal projection of objects of perception with displacement of the inverting device together with the eye. Figure 4 illustrates the schematic diagram of the dynamics of projection relations on the retina corresponding to this situation.

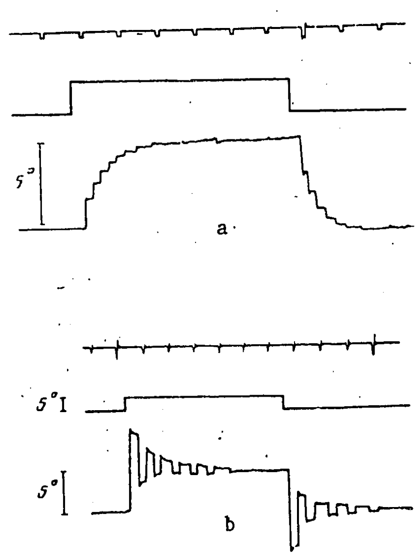

Figure 3.
Tracings of eye movements (horizontal component) while changing fixation points, K_{fb} = -0.3 (a) and -2.4 (b) (stimulus at the top)

Under ordinary conditions (Figure 4a), the eye turns in the direction of object of perception B, and the projection of the object on the retina B' moves in the direction of the fovea O'. When an inverting optical system is placed on the eyeball (Figure 4b), there is a change in relation between the direction of displacement of the projection of the object on the retina and movement of the eye: during the latter, the projection of the object on the retina B' moves away from the fovea in a diametrically opposite direction.

This methodological principle of changing the sign of visual feedback is executed by means of a miniature trapezoid prism with angles of 45° at the base, which is secured to the eyeball with a central suction cup. Placement of the prism causes inverted perception of objects in a visual field of ~40° (Figure 5). The distinctive feature of using an inverting prism is that it permits changing normal spatial relations of images of objects on the retina into opposite ones only along one inverted axis, which is set by the position of the plane of the prism trapeze. The spatial relations of the proximal stimulus, which are perpendicular to this axis, do not change. If the trapeze plane is inclined toward the horizontal line at an angle α, the image of the object on the retina changes by 180° in its position along the axis of inclination; the orientation of the object on the retina along the axis at angle α+90° from the horizontal is retained. By rotating the prism one can change the orientation of the retinal image, and the axis of inversion will determine the vector of change in sign of feedback. In mathematical terms, we can say that transformation of the object image on the retina caused by a trapezoid prism is degenerate or partial inversion.

The method used to attach the prism in the metal tube allows for rotation thereof in relation to the central axis of the suction cup and provides for any orientation of the inverted axis.

Regardless of orientation of the inverted axis, placement of the prism on the human eye disrupts sensorimotor coordination of the OMS and causes appearance of specific forms of oculomotor activity, in particular, nystagmus and high-amplitude sinusoidal oscillations (Figure 6). In this case, there is total loss of stability of perception of the outside world and impairment of human actions performed under visual monitoring.

Optical Change in Direction of Visual Feedback

This method is based on a change in orientation of the entire system of retinal coordinates in relation to objects of perception. Any movement of the eyes in the direction of α will cause shifting of the projection of the object of fixation on the retina in direction $\alpha+\gamma$, where γ is the angle of rotation of retinal coordinate axes. The larger γ is, the greater the discrepancy between directions of eye movement and displacement of image of the object on the retina, and the more difficult it is to perform the oculomotor task (fixing the object). Under ordinary conditions of regulation of eye movements, when the direction of eye movement and displacement of projection of the object on the retina coincide, $\gamma = 0$. In the possible extreme case, when the direction of eye movement and displacement of projection of the object on the retina are diametrically opposed, $\gamma = 180°$. If we arbitrarily separate feedback into negative and positive, it can be assumed that, with $\gamma = 0$ (360°) eye movement is regulated on the basis of negative feedback and with $\gamma = 180°$ by positive visual feedback. Aside from these extreme values, with $0°<\gamma<180°$ and $180°<\gamma<360°$, regulation of eye movements is based on different directions of visual feedback.

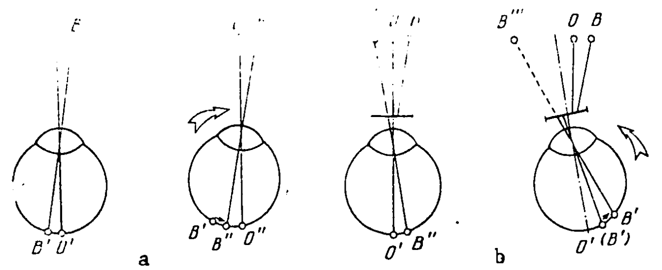

Figure 4. Diagram illustrating displacement of projection of object on retina as a function of direction of eye movement

a) under ordinary conditions
b) with placement of inverting optical system on the eye (solid line)
O,B) objects of fixation
O'B') projection of objects on retina before turning eye
B") imaginary (perceived) position of B in space

The large arrow shows direction of eye movement and the thin one, displacement of projection of objects on the retina

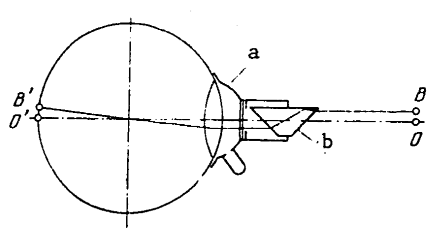

Figure 5.
Diagram illustrating the method of optical inversion of sign of visual feedback

a) eye suction cup
b) inverting prism
OB) object
O'B') projection of object on retina

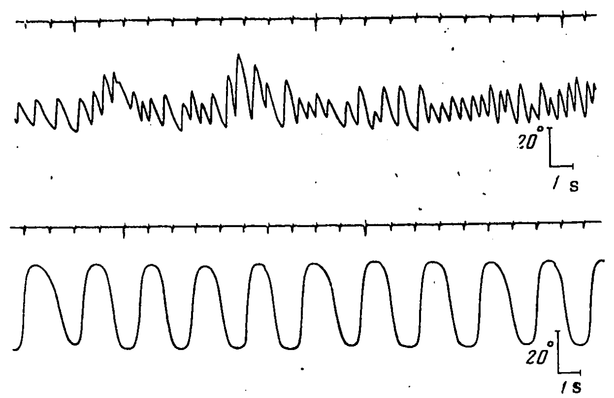

Figure 6. Tracings of eye movements with changes in sign of visual feedback (horizontal component)

a) inversion nystagmus   b) even sinusoidal oscillations

A monotonic turn of the retinal coordinate axes can be obtained by means of an optical system consisting of two trapezoid prisms that successively refract the light rays reflected from the object. In this case, each of the prisms inverts the image of the object along the axis that is parallel to the plane of the prism trapeze, but the overall effect of two inversions causes the retinal coordinate axes to turn by a certain angle γ. The angle of rotation of the axes is determined by the angle of turn of the trapeze plane of one prism in relation to the other. A monotonic turn of the prisms in relation to one another by an angle of $0°-\pm 90°$ (regardless of direction of turn) yields a monotonic turn of retinal coordinate axes by an angle of $0°-\pm 180°$. The absolute orientation of the prisms is unimportant in this case.

In our studies, two miniature trapezoid prisms were attached to a central suction cup (Figure 7). Each prism was put in a separate tube, rotation of which enabled us to alter the position of the plane of the prism trapeze and, accordingly, to set the required angle of rotation of retinal coordinate axes. This optical system provided for perception of objects in a field of vision of about 30°.

Studies revealed that, with monotonic change in direction of OMS visual feedback there is continuous transformation of oculomotor activity, visual perception and customary means of solving perceptual problems. The highest point of such transformation occurs with $\gamma = 180°$, the value that corresponds to regulation of eye movements on the basis of positive visual feedback (complete inversion).

Figure 8 illustrates a tracing of eye movements (horizontal and vertical component) while fixing a specified object ($\gamma = 105°$). We see that, under these conditions, the elementary oculomotor task is performed with difficulty and requires more than 20 s. The trajectory of eye movements consits of a chain of saccadic jumps, rather than the usual 1-2, and they are interrupted by smooth turns. The spatial shape of the trajectory of eye movements is a spiral.

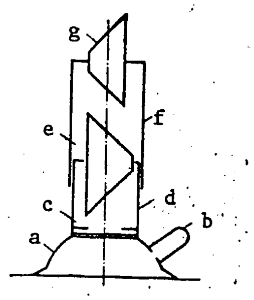

Figure 7.
Diagram of suction cup equipped with optical system, which permits changing the orientation of reginal coordinate axes
a) housing of suction cup
b) bulb to pump air out
c) diaphragm
d) first tube
e) first prism
f) second tube
g) second prism

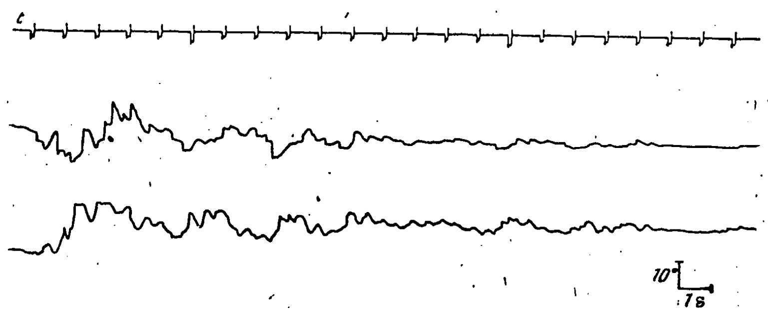

Figure 8. Tracing of eye movements when instructed to fix on a specified point object (γ = 105°)

Optical Stabilization of Projection of Objects on Retina

The idea of this method is taken from the principle that is known in physics of plotting optical systems of stabilization of object projection on a plane whose orientation changes. As applied to the eye, the stabilization effect is obtained when the focus of the converging lens that is situated in front of the eye coincides with the center of eye rotation. In this case, any turn of the eye will not alter the position of the defocused image of objects on the retina. In order to obtain a sharp image on the retina, a diverging lens must be attached to the eye, whose focus is also in the rotation center (Figure 9).

The optical system used in our experiments consists of a negative lens 8 mm in diameter and focus distance of 22 mm, which is attached to the eye by means of a central suction cup, and a positive lens 38 mm in diameter with focus distance of 45 mm, placed on a special eyeglass frame that is stationary in relation to the head. The distance between the positive lens and eye is adjusted with a micrometric screw. After placing and adjusting the optical system, the subject is able to view surrounding objects monocularly, and perceives their dimensions as being somewhat enlarged.

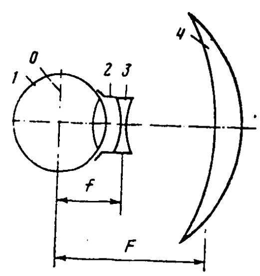

Figure 9.
Diagram illustrating the method of optical stabilization of image of objects in relation to retina

1) eyeball
2) suction cup
3) negative lens
4) positive lens
F, f) focal distance of lenses

A test of this method yielded the following results. When fixing a lit point in darkness there is fluctuation of perceived brightness and occasionally total disappearance of the perceived stimulus. However, even with lengthy examination of real objects under ordinary light, there is no fluctuation or disapparance of the perceived image or parts thereof.

With voluntary switching of eyes to a stationary object situated eccentrically, smooth movement thereof is perceived in the direction of periphery of visual field. Under these conditions, eye movements have a marked, regular [even] component, interrupted by single saccadic movements (Figure 10a).

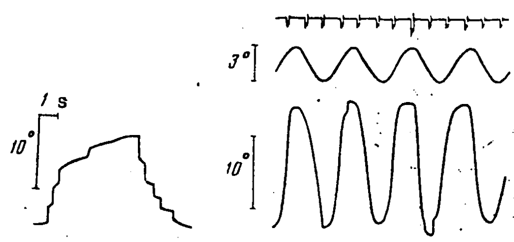

Figure 10. Tracings of eye movements with optical stabilization of object image on retina (horizontal component)

a) when the task is to alternately fix on two stationary point objects
b) when tracking a lighted dot (top tracing) in a mode of periodic oscillation with an amplitude of 3°

When tracking a lighted dot in a mode of periodic oscillations, the eye movements are smooth and they accurately reproduce the frequency of oscillation of the object. The amplitude of eye oscillations and the mean rate thereof are several times higher than the corresponding parameters of movement of the object (Figure 10b).

The facts obtained generally indicate that this method provides a rather high degree of stabilization of object image in relation to the retina. The distinctive feature of this method is that it is possible to transmit oculomotor function to head movements, which permits examination of the patterns of various levels of regulation of movements.

Thus far, we discussed methods that provide independent optical transformation of magnitude or sign (direction of OMS visual feedback). There may also be complex methods of transformation, which imply simultaneous change in both the sign (direction) and magnitude of visual feedback, i.e., its vector. They can be executed by means of complex contact optical devices that provide for multidimensional transformation of projections of objects on the retina. In this case, the unusual distinctions of eye movements, as well as impairment of visual perception, may be more complex in nature.

The above-described methods of optical transformation of OMS visual feedback and some of the results with the use thereof prove that one can examine a wide spectrum of processes of regulation of eye movements and visual perception. By inducing a successive chain of distortions in OMS function, sensorimotor integration in the visual system, correlations between the visual system and vestibular, somatosensory and other systems, transformation of OMS visual feedback emerges as a systems method of experimental research. The main range of problems that can be solved by using methods of changing the sign, direction and magnitude of OMS visual feedback is referable to the properties, mechanism and conditions of OMS adaptation, the role of the OMS in processes of formation of a current visual image, patterns of extrasystemic associations of the visual system and mechanisms of human function.

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PSYCHOLOGY

SOME ASPECTS OF THE HISTORY OF DEVELOPMENT OF SOVIET MILITARY PSYCHOLOGY

Moscow PSIKHOLOGICHESKIY ZHURNAL in Russian No 3, 1980 pp 95-106

[Article by V. A. Karashchan]

[Text] Soviet military psychology is a relatively independent branch of science, which is on the boundary between psychology and military science. It has special features that ensue from the object and subject it deals with; it is based on Marxist-Leninist methodology. One should know the history of inception of military psychology and establishment as a science in order to correctly understand the current content and tasks of military psychology.

The development of Soviet military psychology traveled over a difficult and contradictory route. It followed the steps of social practice that were taken by military affairs as a whole and different types of armed forces in particular. When discussing the history of Soviet military psychology, one must be governed by the following methodological theses: for a long time, military psychology developed in the stream of different branches of science; any stage of development of science serves as a reflection of military and social requirements for it; military psychology, like other branches of psychological science, advanced from purely speculative considerations to scientific experimental research based on objective methods; development of military psychological thought occurred in the presence of a bitter struggle between materialistic and idealistic conceptions.

Bearing these and other situations in mind, the history of development of Russian military psychology can be divided into three main periods. The first period is the prescientific one in development of military psychological thinking (11th century to the end of the 1870's). It covers the time when psychology was not yet formed as a specific system of knowledge, and it consists of three stages: spontaneous [elemental] development of military psychological thinking before the appearance of a regular Russian army (11th century to first quarter of the 17th); empirical accumulation of facts and formalization of military psychological views by progressive military figures in written sources and documents (1730's to 1850's); development of military psychological views with the use of data in general psychology and other disciplines (1860's-1870's).

The second period (1880's-1890's to the 1900's prior to the Great October Revolution) is referable to inception and initial formulation of military psychology as a science. Some problems of military psychology began to form a system of knowledge, which led to formation of an independent branch of science, military psychology.

The late 19th and early 20th century were marked by a marked increase in the Russian army's interest in military psychology. This was attributable to several reasons. In the first place, the armies became very large and their technical capabilities grew. In the second place, exacerbation of class contradictions in the army and nation as a whole made it imperative to alter the ways and means of ideological handling of personnel. In the third place, development of general psychology broadened considerably the scientific base and possibilities with respect to solving a number of problems of military psychology, including socio-psychological ones.

This period is divided into two stages: inception of military psychology (1880's-1890's) and initial formation of military psychology as a science (early 20th century, prior to the October Revolution).

The third period (1917 to the present time) is referable to establishment of military psychology on the methodological basis of Marxist-Leninist philosophy, and it consists of four stages: inception of Soviet military psychology (1917-1940); military psychology during the years of the Great Patriotic War (1941-1945); formation of military psychology in the postwar years on the basis of generalization of combat experience (1945 to the early 1950's); development of Soviet military psychology under contemporary conditions (from the mid 1950's to the present).

The appearance of Soviet military psychology is inseparably linked with the combat performance and building of the worker-peasant Red Army, at whose cradle stood V. I. Lenin. He elaborated the basic methodological theses, on the basis of which military psychological views emerged and developed. At the threshold of the revolutionary battles of 1905-1907, V. I. Lenin had already offered, in some of his works, the basic theses for military training of the proletariat for the forthcoming armed uprising [1]. He considered the main objective of such training to be political education and psychological preparation of the masses for armed combat. He wrote, "The masses must know that they are heading for a bloody, desperate armed battle. Defiance of death must spread among the masses and assure victory" [2]. Somewhat later he recalled that, in any war, victory is ultimately determined by the spirit of the masses who shed their blood on the battlefield.

V. I. Lenin, who directly supervised the building of the Red Army and its combat actions, repeatedly recalled that the training of Red Army personnel should not be reduced solely to professional training. It must also include comprehensive development of the soldier's spiritual resources. And a soldier can improve them only through practical activity, combat, which "reveals to him the measure of his capabilities, expands his outlook, improves his abilities, clears his mind and forges his will" [3]. In our days, the advice of V. I. Lenin concerning the need to study the needs, aspirations and mood of revolutionary and Red Army masses, means of affecting their psychology and importance of such work, particularly in a combat situation [4] sounds timely.

These and other ideas of V. I. Lenin played a decisive role in the formation of Soviet military psychology. Because of them, at the stage of its inception it had fundamental theoretical-ideological and methodological bases. This was all the more important since the process of development of military psychology was taking place during the bitter battle with idealistic psychology. This was a stage of creative search, but sometimes gross mistakes, the roots of which were in the theoretical weakness of general psychology and small number of specialists in military psychology, as well as their poor Marxist training. The nature and distinctions of the struggle on the military psychological front were also complicated by the fact that there were many old military specialists in the ranks of the Red Army. Many of them were outstanding experts in military affairs, and for this reason were called upon to serve as instructors at academies and to author works dealing with military theory and psychology. They tried to grasp Marxist theory, but ideological rearmament proceeded very slowly. In the expression of V. I. Lenin, they were permeated through and through with bourgeois contemplation of the world [5], and this did not allow them to completely take dialectial materialistic positions.

This was very graphically manifested in the activities of old military psychologists, such as G. F. Girs, L. Byzov, P. I. Izmest'yev, A. N. Suvorov and others. They tried to define the subject and take a new approach to pressing problems of military psychology: formation of high moral and combat traits in personnel, substantiation of new methods of educating and training servicemen, leadership of units [chasti] and subunits [podrazdeleniya] in combat, strengthening military discipline and correct understanding of sociomilitary questions [6]. He realized that one could not solve new problems from the vantage points of old military psychology. But the fact of the matter was that the first Soviet military psychology did not usually know a scientific method of learning, dialectical materialism. The task of reorganizing psychology on the basis of Marxist-Leninist methodology had not yet been formulated, and most psychologists did not realize that it was needed. For this reason, they tried to make use of the rational elements of old psychology and to advance some of their own ideas that would best meet the new social and political conditions. Their criticism of prerevolutionary military psychology was more intuitive than deliberately scientific. In 1918-1920, 42 works were published in this light, and many of them (14) dealt with problems of military social psychology, to which much importance was attributed at that time. The situation was also complicated by the fact that new military psychological directions (reactology, reflexology, psychoengineering), advanced in the ideological struggle against idealism, were related to mechanistic views, and this generated new mistakes. It was not possible to detect and reveal this mistakes, since there were still not real Marxist psychologists. As a result, the struggle against idealism in science became a struggle against military psychology itself; for this reason, instruction of the course of military psychology was discontinued in 1924, and articles appeared in the press that harshly critized not only its content but even its name.

Some problems of military psychology were formulated and solved the most fruitfully in the 1920's by the outstanding regiment leader ["polkovodets"], M. V. Frunze. In his works, he developed and defined the theses of V. I. Lenin concerning military affairs, the role of the masses and personality in war. "Our Red Arm," wrote M. V. Frunze, "must be prepared both technically and psychologically to resolve military problems" [7].

Governed by the instructions of V. I. Lenin and considering the needs of practice, M. V. Frunze formulated and methodologically solved problems pertaining to the role of psychological stability of personnel, psychological training for combat, combat traits of personnel; and indicated that combat equipment, along with purely material and physical results of its use, has a strong influence on the mind of people involved in battles, that many times success is not determined by the fact that a part of the enemy's ranks is physically removed, but that this has a moral effect on the remaining combatants, destroying their capacity to resist [8]. Unfortunately, the military psychologists of the 1920's did not make use in their work of these methodologically correct theses of M. V. Frunze.

Concurrently with theoretical and methodological work on problems of military psychology, practical work was also being done in the Red Army. This was largely aided by the development in the mid 1920's of a broad network of central and peripheral psychophysiological laboratories, in which work was begun on psychological-pedagogic problems of military education and training. Military psychologists were engaged in research on psychophysiological characteristics of performance by various military specialists (drivers, aviators, infantrymen, tankmen); they developed and refined methods of occupational screening; they made up professiograms for some of the military specialties (pilot, artillery man, machine gunner); they developed methods of psychological and physical exercise to improve efficiency and reduce fatigability in the course of diverse forms of military work.

The staffs of these laboratories were able to work out several important practical questions and recommendations. This is convincingly illustrated by the subject matter and number of publications. Thus, while only 42 works were published in 1918-1920 and they were mainly of a theoretical nature, in the next five years their number more than doubled, while the content of most of them reflected the results of practical studies in the troops. Already in 1921, the aviation physician and psychologist, S. Ye. Mints, opened a laboratory for the study of psychological distinctions of pilot work, their individual traits, emotional stability, as well as for mass scale psychological screening of candidates for flying schools.

In several of the publications, the authors did not merely appeal for the use of psychological pedagogic knowledge in the education and training process for Red Army soldiers, but offered suggestions for improvement of specific forms of combat training for the purpose of psychological toughening of personnel: "we study the techniques of nocturnal operations, we become used to their distinctions, but we seldom use night exercises as a method of psychological training of a solder and unit" [9]. The well-known pilot, I. Pavlov, developed the same idea with reference to the training of flight personnel with due consideration of class psychology and political orientation: "... each teacher and, especially, instructor must be a sort of psychologist" [10]. Further, he maintains that "the pilot can only achieve a high moral state when ... his consciousness has learned completely the ideas of Soviet power, so that he would be fully aware of what he is doing when he sacrifices himself" [11].

N. M. Dobrotvorskiy made a large contribution to development of problems of psychology of flying work. From 1925 on he headed the Central Psychophysiological Laboratory of the Air Force. He published 17 works, and many of the issues raised in them have not lost their timeliness in aviation and military psychology to this day. Thus, long before the appearance of engineering psychology, he was in favor of adopting a standard aircraft cabin and substantiated the need for rational arrangement of instruments.

For a long time, B. M. Teplov, who headed a group of psychologists (A. A. Smirnov, P. A. Shevarev and others), worked on military camouflage problems. The results of these studies were published in the 1920's in the journal VOYNA I TEKHNIKA

[War and Technology], and they found broad practical applications in the years of the Great Patriotic War [12].

Analysis of military periodical publications of the 1920's shows that not only scientists, but practical workers in the artillery, infantry, engineer and other units [13] worked extensively on different problems of psychophysiology of military work and professional screening. Many studies were conducted directly in the field, and for this reason had some practical value. The work of the psychophysiological laboratories was summarized in several publications: "Psychophysiological Substantiation of Training and Educating Servicemen" (1927), "Data on Psychophysiology of Work in the RKKA [Workers' and Peasants' Red Army]" (1933), "Flying Work" (1930). On the whole, the number of laboratories in the entire RKKA increased from 3 to 24 in 1924-1928, and accordingly, the number of skilled workers in them grew from 14 to 115, while the total number of individuals submitted to psychophysiological tests exceed 200,000 [14].

At the same time, it must be noted that these studies did not always take into consideration the methodological change in general psychology, which Soviet psychologists were making under the influence of Marxist-Leninist theory. Research and practical work in the field of military psychology was pursued up to 1936. Thereafter, the psychophysiological laboratories were eliminated because of erroneously equating industrial psychology and psychotechnics with pedology. This immediately affected the number of publications: 6 in 1937, 3 in 1938, 7 in 1939 and 2 in 1940; most of the authors were aviation psychologists.

Actually, it is only in the area of aviation psychology that scientific research continued. This was needed because of the specifics of flight work, mass-scale rearmament of the Air Corps with new types of aircraft and drastic increase in their number. In 1936, a branch of the Institute of Aviation Medicine imeni Academician I. P. Pavlov was opened at the Kachinskaya Flying School. The staff of this branch, under the leadership of K. K. Platonov, conducted work that laid the first methodological and theoretical foundations of aviation psychology. This was a turning point in military psychology, the beginning of its complete move from reflexolog and reactological methodology to that of general psychology, which had by then taken the positions of Marxist-Leninist philosophy. This was aided by the fact that the staff included, in addition to military specialists and pilot methodologists, staff members from the Institute of Psychology, L. M. Shvarts, Ye. V. Gur'yanov and V. V. Chebysheva. This branch was given the task to study pilot tension during flights and psychological substantiation of pilot training on trainers [15]. But first, the staff of the branch had to overcome the mechanistic methodology of simulators and training in the military department of the Central Institute of Labor, the flaws of which were already obvious. This task was perfromed from the vantage points of theory of formation and transfer of skills.

In addition to research, this team conducted pedagogic work to disseminate military psychological information among the personnel of the Air Corps, and this ended with publication of the first educational textbook of aviation psychology [16].

Many of the flaws and mistakes in development of military psychology were due to the difficulty of converting to a new methodological basis, underestimation of its practical importance and shortage of personnel who had assimilated Marxist-Leninist theory. These difficulties were also reflected in the discussion that was deployed concerning definition of the subject of military psychology. It was started with the article of A. A. Talankin, "The Problem of 'Military Psychology' in Our Military Literature" (January 1926), in which he analyzed the theoretical and methodological positions of different psychologists who accepted without criticism the idealistic theses of foreign and Russian military psychology [17]. In this regard, he proposed that military psychology, which he viewed only as bourgeois psychology, be entirely eliminated, and stated that "with respect to textbooks of military psychology, we can only express satisfaction that they do not exist at all in the Red Army. The scientific value of such textbooks is quite doubtful, not to say more" [18]. M. Korol' expressed his valid objection to this: "Not only do we fail to share this author's happiness about the fact that we have no textbooks of military psychology, we even believe that ... comrade Talankin dealt very correctly with the bourgeois substance of military psychology, but at the same time he threw the baby away with the bath water" [19].

However, it is not this external aspect that is decisive. The value of the debate that continued for several years was that, as it proceeded, such important questions as the significance of Marxist philosophy to definition of the subject, methods and tasks of military psychology were formulated and in part solved; to some extent there was definition of its range of problems and area of research in order to solve practical and theoretical problems of the RKKA.

A. A. Talankin, G. D. Khakhan'yan, V. Rubtsov, N. M. Dobrotvorskiy and others were the most active in working on these problems.

A. A. Talankin was the first to present and substantiate a program for reorganizing Soviet military psychology on a dialectical materialistc basis, and the requirement that dialectics be applied to military psychological research. He was right in stating: "It is important for us to determine that not a single author referred to the system of Marxist psychology in formulating problems of 'military psychology'" [20]. In the same article, A. A. Talankin very correctly indicated that future development of military psychology depended on the methodological and materialistic positions of psychological science as a whole: "formulation of the problem of 'military psychology' in all its breadth ... depends on formulation of the problem of psychology in general in Marxism" [21].

In the course of this debate, not only did opinions emerge on the subject of military psychology, but there was further development of the views of its participants themselves. This is graphically illustrated by the evolution of views of G. D. Khakhan'yan and A. A. Talankin.

At first, A. A. Talankin tried to find in human behavior, as the subject of military psychology, only the relationship between biological and social factors corresponding to inborn and acquired reactions. He said nothing at all about human consciousness. Backward schemes of empirical psychology prevented him from seeing the dialectical unity of inborn and acquired, biological and social factors.

Yet 2 years later he submitted to critical analysis the reflexological approach to the subject of military psychology and, first of all, indicated that the reflexologists (M. Korol', Yu. P. Frolov, Tsiffer) exaggerate the biological element of behavior of a soldier to the detriment of the social factor, and they overlook his consciousness [22]. This was a very important moment in the history of inception of the subject of Soviet military psychology, since the correct assessment of the place and role of consciousness in the performance of a fighting man led to restoration of the rights of consciousness as a subject of military psychological studies.

Subsequently, A. A. Talankin developed and deepened his conception of the subject of military psychology in theoretical papers and articles. He maintained that "penetration of Marxism into the area of military affairs must deal in particular with such lofty military theoretical thought as the system of ideas of 'military psychology,' ... which has still been virtually untouched by Marxist methodology" [23].

The thesis of A. A. Talankin on activity of the consciousness was also developed at that time by other military psychologists. They showed how, in their opinion, one should approach definition of the subject of military psychology against the background of Marxist criticism of the basic tenets of reflexology, mechanicism and remnants of idealism in the development of science.

Discussions of the books of G. D. Khakhan'yan [24] and A. A. Talankin [25], which took place at the Central House of the Red Army imeni M. V. Frunze in the presence of the broad military and scientific community were most fruitful and prominent in development of the views of military psychologists of the subject, methods and tasks of military psychology [26]. These discussions went beyond the framework of the outlined problems, and they assumed the guise of extensive debates on current issues that determined the development of Soviet military psychology.

Their study of the philosophical heritage of K. Marx, F. Engels, V. I. Lenin and, in particular, the book by F. Engels, "Dialectics of Nature" published in 1925 and excerpts from the "Philosophical Notebooks" of V. I. Lenin, played a decisive role in the subsequent theoretical work of military psychologists on the problem of the subject of this discipline. Expressly this helped them comprehend the specifics of the psyche, the consciousness of the Red Army man as a reflection of objective reality occurring during military activities and included in this activity as its regulator; it helped overcome mechanistic interpretation of behavior and idealistic interpretation of the psyche, and turn to concrete studies of consciousness and the psyche of Red Army men under different conditions of military service. Because of this, some important steps had already been made in the 1930's toward developing methodological approaches to definition of the main problems of the subject of military psychology from the positions of Marxist-Leninist teaching on war and the army.

In overcoming idealism, reflexological and reactological "behaviorism" in interpretation of the psyche, already in the mid 1930's the military psychologists made an important contribution to development of dialectical materialistic interpretation of the personality of the Red Army man, and this enabled them to shed new light on the question of the subject of Soviet military psychology.

The system of training the troops began to undergo active change in the late 1930's to conform with the requirements of new technology and military science. In January 1941, the USSR People's Commissar of Defense set the task of accelerated development of this discipline in order to lay the psychological foundation for combat and political training. Execution thereof hindered the aggression of fascist Germany. During the years of the Great Patriotic War, the Communist Party attributed first and foremost importance to instilling in soldiers infinite loyalty to their Soviet Homeland, hatred for the invaders, high combat activity, decisiveness in the battle against the enemy, fearlessness and mass scale heroism. Under these conditions, the work of military psychologists and all psychological science was governed by the needs of the front. Such questions as analysis of combat performance, education and upbringing in the combat traditions of the Russian and Soviet army, volitional traits of soldiers, training of different mental functions of fighting men, endurance and control of fatigue were raised and discussed on the pages of the military press.

Civilian psychologists made a significant contribution to work on problems of military psychology for the needs of the front. They participated actively in military psychological research on formation of a soldier group, studies of distinctions of performance and traits of commanding personnel, psychology of battles, special training for combat activity, etc. [27].

The psychologists solved a number of important practical problems during the war years because of their theoretical maturity and methodological competence for conducting the most complex military psychological studies. The active participaatin in this work of prominent Soviet scientists (B. M. Teplov, "On the Question of Practical Thinking--Psychological Study of the Thinking of a Regiment Commander According to Military History; A. S. Prangishvili, "Psychology of Panic") strengthened the methodological foundations of military psychology, consolidating its ties with general psychology [28].

In the course of the Great Patriotic War, military psychologists began to analyze and summarize combat experience. There was an increase in number of in-depth military psychological studies based on material referable to the front lines. A. K. Perov defended a dissertation entitled "Psychology of Courage and Fear as Related to the Question of Temperament" (study of a soldier on the front in 1941-1945). Overview articles were published: "Emotional Reactions in a Combat Situation," by A. A. Midadze; "Aviation Accidents Related to the Mental State of Pilots," by D. R. Lunts; "Psychosis of Wartime," by A. K. Lents; "Borderline States of Wartime," by V. N. Myasishchev, and others.

Right after the war ended, the Communist Party and Soviet government put a task to military personnel, to acquire skill in teaching and rearing subordinates under new conditions, to creatively assimilate combat experience. Most commanders and political workers understood correctly the practical significance of military psychology to performance of this task. In the troops, there was increased interest in military psychological problems. In the 1946/47 school year, a course of military psychology and pedagogics was started at all military educational institutions, and this in turn activated research work and increased the demand for literature on military psychology [29].

The first few postwar years were characterized by improvement of material, technical and organizational conditions for the development of military psychological thought. Chairs of military psychology and pedagogics were established at the Higher Military Pedagogic Institute imeni M. I. Kalinin, Military Pedagogic Institute of the Soviet Army and Military Institute of Physical Culture and Sports imeni V. I. Lenin, where postgraduate classes were also used to train scientific cadres of military psychologists.

A department of experimental psychology was opened at the Scientific Research and Testing Institute of Aviation Medicine; its staff headed by K. K. Platonov made a major contribution, not only to development of aviation psychology, but in the area of development of new methods and equipment for psychological studies. This work resulted in creation of several aircraft-laboratories in the mid 1950's, for the special purpose of organizing scientific work on psychology of flight work. In addition to instruction, the instructors and postgraduate students on the chairs of military psychology and pedagogics of military pedagogic institutes also pursued much scientific research, in which well-known Soviet psychologists participated actively: B. G. Anan'yev, A. N. Leont'yev and D. B. El'konin. They assisted the military psychologists by delivering lectures, working out courses, training scientiifc personnel and preparing the educational-material base. Such topics were studied on these chairs as performance and skills, psychology of training exercises when teaching how to fire a rifle, thinking processes when solving educational problems, psychological analysis of the process of reading a topographic map, psychology of formation of volitional action, military ideals of students at Suvorov military colleges, psychological analysis of the feats of Soviet soldiers [30]. Articles appeared in the periodic press whose authors tried to disclose more deeply than was done before the psychological bases of training Soviet solders and to demonstrate the bases of their cognitive activity in the studying process.

In May 1950, the first scientific conference on Soviet military psychology convened in Leningrad. The following papers were delivered and discussed: "The Subject of Soviet Military Psychology, Its Tasks and Methods," by G. D. Lukov; "Tasks for Soviet Military Psychology in Aviation," by K. K. Platonov; "Principles Involved in Preparing a Course on Soviet Military Psychology," by D. B. El'konin; and "Reactionary Substance of Modern American Military Psychology," by T. G. Yegorov. These were cardinal issues, and continued development of this discipline depended on resolution thereof. During the conference there was mention of the positive aspects of development of military psychology and demonstration of flaws. The main ones were the rift between military psychological theory and practice in the troops, insufficient attention given to the study of combat experience during the Great Patriotic War, incorrect attitude toward the teaching of I. P. Pavlov, unsatisfactory set-up of experimental work and others. This conference showed that Soviet military psychology, governed by Marxist-Leninist theory, was capable of solving deeper problems of psychological analysis, substantiation and refinement of personnel training, as well as of exposing the reactionary essence of modern bourgeois military psychology [31]. The conference participants arrived at the unanimous opinion that "the subject of Soviet military psychology is the psyche of Soviet man engaged in military activity" [32]. It was also clarified, and this was of methodological importance, that military activity has a formative effect on the fighting man's personality and behavior. This was an important stage on the way toward establishing the subject of Soviet military psychology.

Implementing the decisions of this conference, G. D. Lukov and T. G. Yegorov prepared textbooks of military psychology, which were subsequently revised to include the results of new research [33]. The idea of T. G. Yegorov about the role of the soldier group in the formation of the soldier's personality, relating it to the Soviet Army as a whole, was an important and new element in these textbooks, which defined and even developed the subject of this discipline. This was a continuation of the line initiated in Russian military psychology by the research of V. M. Bekhterev and his disciple, G. Ye. Shumkov, on the sociopsychological aspects of military affairs. The results of numerous military psychological studies conducted in the 1950's were described extensively in the summary works of G. D. Lukov and K. K. Platonov [34]. Subsequently, their material was used in a new textbook [35]. These works played an important role in development of military psychology. More than one generation of Soviet officers were brought up with their use, gleaned psychological knowledge and advanced their general cultural level. This was the small step, with which began a qualitative phase of development of Soviet military psychological thought.

Along with the advances in Soviet military psychology in the postwar years, we must mention the flaws inherent in that period: lack of psychological substantiation of knowhow in troop training with the use of new forms of combat equipment and weapons; there was virtually no study of problems of social psychology and psychological training of personnel for combat in a modern war; there were few general theoretical and methodological studies that were extremely necessary for rapid development of the science and military practice.

The revolution that had begun in military affairs and the radical transformations in all sectors of military building, as well as the increasing need for officers to have military psychological knowledge presented new demands of military psychology.

In the late 1950's to early 1960's, several steps were taken by the Armed Forces to meet these demands. In 1959, the chair of military pedagogics and psychology was founded at the Military Political Academy imeni V. I. Lenin; it became the center for development and psychological substantiation of problems of military instruction and training of Soviet soldiers under new conditions. A number of important military psychological studies was conducted on this chair, in particular, those dealing with the following problems: development of thinking in military school students at tactical classes; formation of relations between members of a soldier group on the basis of the requirements of military manuals; inculcating a communistic world outlook in Soviet soldiers; psychological distinctions of training of radar station operators, individual approach to the rearing of Soviet soldiers, psychological bases of strengthening military discipline, psychological and pedagogic bases of formation of propaganda proficiency in political worker-officers, etc.

A qualitatively new phase began in development of this science. First of all, this is indicated by the appearance of naval and military engineering psychology [36]. There was resumption and considerable deepening of studies in the areas and directions that had been stopped in the 1930's because of methodological difficulties in military social psychology, psychological screening, psychological training; increasing attention was devoted to methodological problems of military psychology as a whole and different aspects thereof. The continued development of military psychology is also confirmed by analysis of the topics of scientific research and publications. Thus, while 140 works (average of 12 per year) were published in the 1950's, there were already about 1100 (about 90 per year) in the 1960's. In the 1970's, more than 120 works were published annually. And this analysis is not only indicative of the quantitative growth of military psychological research, but qualitative growth as well. It is expressly during these years that more than 70 doctoral and candidatorial dissertations were defended. Numerous textbooks, educational aids and monographs were published. Military psychology developed in both breadth and depth. This was largely aided by the establishment of chairs of military psychology and pedagogics (late 1960's to early 1970's) at higher military and political schools. They became the center for development of psychological and pedagogic problems of political party work, education and upbringing of soldiers with due consideration of the specifics of forms of armed forces.

In the 1970's, military psychologists performed important work in the area of summarizing the route traveled by this discipline, analysis of accumulated knowhow and introduction thereof in the practice of combat and political training of troops. In-depth theoretical and many applied studies were conducted, the results of which were reflected in a number of fundamental works, textbooks and monographs [37]. Much work was done in the area of studying and disseminating military psychological information at military schools, where an independent course of military psychology and pedagogics was introduced. A similar course (40 and 60 hours on different faculties) was included in programs of universities of Marxism and Leninism. Pressing problems of military psychology are studied in courses for retraining commanders and political workers.

At the present time, the demands of Soviet military psychology have grown in connection with the decisions of the 25th CPSU Congress. In the presence of the difficult [complex] international situation, danger of military adventures on the part of imperialists, intensification of the ideological struggle between socialism and capitalism, it is particularly important to study the psychological bases of the complex approach to training Soviet soldiers, forming a scientific world outlook in them, communistic conviction, active vital position, Soviet patriotism and proletarian internationalism, hatred of imperialists, vigilance and combat readiness. Questions of psychology of leadership and moral psychological training of personnel for combat actions in a modern war, psychological substantiation of new ways and means of learning how to use combat equipment and weapons, professional screening of military specialists are also important [pressing].

Thus, Soviet military psychology, which is presently on the upswing, is an active participant in solving the most important problem put by the USSR Constitution to the Armed Forces: "To reliably protect the Socialist Homeland, to be in constant combat readiness assuring the immediate repulsion of any aggressor" [38].

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SCIENTIFIC CONFERENCE OF THE GOR'KIY DEPARTMENT OF THE SOCIETY OF PSYCHOLOGISTS

Moscow PSIKHOLOGICHESKIY ZHURNAL in Russian No 5, 1980 pp 152-153

[Article by N. A. Alekseyeva]

[Text] A scientific conference of the Gor'kiy department of the Society of Psychologists on the topic of "Some problems of Education, Upbringing and Development" convened on 31 January and 1 February 1980. Among the active participants were instructors from the Gor'kiy Pedagogic Institute, as well as the staff of the chairs of pedagogic and age-related psychology on the psychology faculty of Moscow State University.

The paper of V. Ya. Lyaudis (Moscow) analyzed the structure and functions of a certain type of educational interaction between teacher and students, with which optimum conditions are created for development and enrichment of motivation for learning.

E. A. Reshetova (Moscow) devoted her paper to the problem of formation of theoretical thinking in students in the learning process. The students developed a systems type of orientation in the subject, which altered substantially their conception thereof.

L. F. Obukhova (Moscow) shed light on the current status of the relationship between child education and development. In particular, she analyzed the experimental findings obtained in recent years at the Geneva School of Genetic Psychology and Soviet Science.

N. G. Salmina (Moscow) discussed the role of modeling in educational work.

A. I. Podol'skiy (Moscow) reported the results of experimental and theoretical studies of mechanisms of reduction of mental activity.

The paper of N. A. Alekseyeva (Gor'kiy) dealt with analysis of the activity approach to formation of sensory abilities in preschool children (on the example of modeling [with clay]). As a result of a teaching experiment, the children developed the ability to act independently under new conditions: to distinguish the general [common] structure of objects and to discern means of reproducing a model from the external features of objects.

A. G. Liders (Moscow) submitted the results of an experimental study of how sets are compared by children 5-10 years of age.

In his report, I. M. Sokolov (Gor'kiy) commented on the importance of spatial perception and graphic-spatial thinking to the process of human development and education. In this regard, some modern theories of spatial perception were submitted to critical analysis, and the range of unsolved problems was defined.

L. S. Kolmogorova (Moscow) demonstrated that some forms of materialization (physical [tangible], graphic, symbolic) offer different possibilities of determining essential relations demonstrated in a child's actions, and for this reason they have different influences on orientation of students in their assignments.

I. G. Miloradova (Moscow) stated that acquisition of knowledge about classes of objects and their external features (minerals) is possible without the use of the minerals themselves as an example and object of action.

N. G. Komratova (Gor'kiy) discussed the mental development of older preschool children in the process of gaining knowledge about simple technical equipment.

A. I. Tasminskiy (Kstovo) delivered a paper entitled "Experience in Formation of Systems Conception of the Subject of Educational Activity" (based on data referable to the economics of capital construction).

V. I. Bogdanova (Gor'kiy) ("Social Determination of Early Forms") submitted the results of experimental education of blind deaf-mute children.

L. V. Antakova (Gor'kiy) reported on the effects of motor activity on development of speech in infants.

A. P. Chernov (Gor'kiy) discussed the results of studies of age-related and individual distinctions of school children related to solving spatial problems.

The papers of U. V. Ul'yenkova and N. A. Zhulidova (Gor'kiy) dealt with the problem of studying children with low learning capacity. U. V. Ul'yenkova offered theoretical substantiation for the problem of early compensation of retarded mental development in children; she defined the main directions and routes for solving the psychological pedagogic aspect thereof.

N. A. Zhulidova discussed some of the results of experimental studies of mental development of lower-grade school children with poor learning capacity as related to content of education.

T. I. Chirkova (Gor'kiy) tried to disclose the mechanism of "penetration" of temperament into all forms of activity in her paper, which dealt with the problem of studying the child's temperament from the standpoint of activity theory.

L. A. Kudrina (Gor'kiy) shed light on the problem of determining individual typological differences in the functional state of students. She described the changes in functional state of the nervous system in the course of the day among students at a pedagogic institute.

The paper of V. Kh. Shcherbinina (Gor'kiy) dealt with the question of formation of independent ethical opinions in young [teen-age] students (on the example of teaching literature).

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TITLES OF CANDIDATORIAL DISSERTATIONS DEFENDED IN 1979

Moscow PSIKHOLOGICHESKIY ZHURNAL in Russian No 5, 1980 pp 154-155

[List]

[Text] PSIKHOLOGICHESKIY ZHURNAL [PSYCHOLOGICAL JOURNAL], along with other publications, plans to list regularly the topics of candidatorial dissertations that have been defended (in chronological order) in order to acquaint the scientific community with the subject matter of scientific works dealing with psychology.

General Psychology

Kruglova, I. F. "Voluntary Regulation as Means of Improving Reliability of Performance in the Presence of Fatigue." Scientific advisor: O. A. Konopkin, doctor of psychological sciences.

Shlychkova, A. I. "Correlation Between Involuntary and Voluntary Memory as Related to the Distinctions of Retention and Actualization of Retained Material." Scientific advisor: Prof A. A. Smirnov, doctor of psychological sciences, active member of the USSR Academy of Pedagogic Sciences.

Zakharov, V. P. "Differential Psychological Study of Intellectual and Activational Characteristics of Engineers." Scientific advisor: Docent I. M. Paley, candidate of psychological sciences.

Mileryan, V. Ye. "Study of Correlations in Development of Cognitive Abilities and Dynamic Personality Traits in Senior Class Students." Scientific advisor: Prof A. V. Skripchenko, doctor of psychological sciences.

Radzikhovskiy, L. A. "Main Stages of the Scientific Creativity of L. S. Vygotskiy." Scientific advisor: Prof V. V. Davydov, doctor of psychological sciences, academician of the USSR Academy of Pedagogic Sciences.

Ivanova, Ye. I. "Functional Asymmetry of the Human Cerebral Hemispheres in Visual Recognition." Scientific advisors: Prof Ye. D. Rybalko, doctor of psychological sciences, and Ya. A. Meyerson, candidate of medical sciences.

Baturin, I. A. "Influence of Success and Failure on Functional State and Results of Performance." Scientific advisor: Prof A. A. Krylov, doctor of psychological sciences.

Dzhaparidze, Z. S. "Study of Structural Aspects of Personality Set in the Presence of Poorly Structured Visual Stimulation (Rorschach 'blots')." Scientific advisor: Prof V. G. Norakidze, doctor of psychological sciences, honored scientist of the Georgian SSR.

Sopov, V. F. "Effects of Individual Personality Distinctions and Methods of Psychological Influence on Mental State During Monotonous Activity." Scientific advisor: I. A. Khudarov, candidate of pedagogic sciences, and P. A. Zhorov, candidate of psychological sciences.

Sakvarelidze, R. T. "The Question of Word Meaning and Psychological Mechanism of Semantic Interference." Scientific advisor: Prof A. G. Baindurashvili, doctor of psychological sciences.

Kukubayeva, A. Kh. "Study of Individual Distinctions of Motor Activity and Emotionality During Spontaneous [Natural] Activity." Scientific advisor: Docent I. M. Paley, candidate of psychological sciences.

Social Psychology

Fuentes, Avile Mare "Influence of Solidarity and Level of Development of a Group on Efficiency of Labor." Scientific advisor: O. I. Zotova, candidate of psychological sciences.

Sosnin, V. A. "Studies of Social Conflict in Social Psychology of the United States," Scientific advisor: P. I. Shikhirev, candidate of philosophical sciences.

Abzianidze, Sh. G. "Divergent Behavior and Formation and Change in Social Sets in the Course of Socialization of the Personality." Scientific advisors: Prof A. G. Baindurashvili, doctor of psychological sciences, and R. L. Kvarukhala, candidate of psychological sciences.

Zozul', V. A. "Psychological Distinctions of the Authority of a Subordinate in Management of Work of Internal Affairs Agencies." Scientific advisors: A. V. Petrovskiy, doctor of psychological sciences, and Prof G. G. Zuykov, doctor of psychological sciences.

Avdeyev, V. V. "Sociopsychological Study of Conformity of Functional Role Expectations in Groups." Scientific advisor: A. S. Morozov, candidate of psychological sciences.

Kharshiladze, M. I. "Influence of Interpersonal Relations on Group Performance." Scientific advisor: Prof Sh. A. Nadirashvili, doctor of psychological sciences.

Tamm, Ya. F. "Use of Typologization Procedures in Sociopsychological Studies of Personality." Scientific advisor: Prof V. A. Yadov, doctor of philosophical sciences.

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TOPICS OF SCIENTIFIC RESEARCH DEALING WITH PSYCHOLOGY

Moscow PSIKHOLOGICHESKIY ZHURNAL in Russian No 5, 1980 p 155

[List]

[Text] 76034533. "Psychology of Communication." Institute of Psychology, USSR AS [Academy of Sciences], 1980.

76034534. "Psychological Mechanisms and Forms of Social Behavior in a Developed Socialist Society." Institute of Psychology, USSR AS, 1980.

76034526. "Methodological and Theoretical Bases of Industrial and Engineering Psychology." Institute of Psychology, USSR AS, 1980.

76034523. "Development and Operation of System of Data Gathering and Processing; Control of Psychological and Psychophysiological Experiments." Institute of Psychology, USSR AS, 1980.

76034528. "Psychological Problems of Controlling Moving Objects." Institute of Psychology, USSR AS, 1980.

76034528. "Mathematical Models as a Research Method in Psychology." Institute of Psychology, USSR AS, 1980.

78052487. "Mechanisms of Color Vision." MGU [Moscow State University], 1980.

78052488. "Pathopsychological Analysis of Disturbances of Mental Processes in General and Pediatric Pathopsychology." MGU, 1980.

78052489. "Neuropsychological Analysis of Restoration of Mental Processes in Cases of Local Brain Lesions." MGU, 1980.

78052490. "Psychological Bases of Education and Upbringing." MGU, 1980.

78052491. "Neuropsychological Analysis of Mental Processes in the Presence of Local Brain Lesions." MGU, 1980.

78052492. "Neuronal Mechanisms of Functional State." MGU, 1980.

78052494. "Psychophysiological Studies of Impaired Mental Processes in the Presence of Local Brain Lesions." MGU, 1980.

78052495. "Elements of Animal Behavior and Sensory Activity as Related to Development of Robots With Elements of Artificial Intelligence." MGU, 1980.

78052497. "Study of Patterns of the Process of Acquiring Knowledge." MGU, 1980.

78052498. "Development of Theoretical and Methodological Bases of Ergonomics." MGU, 1980.

78052501. "Psychological Problems of Trainee's Contact With Technical Language." MGU, 1980.

78052505. "Study of Performance of 'Eye-Hand' System." MGU, 1980.

78052506. "Modeling, Formation and Study of Main Properties and Patterns of Educational Activity. Development of Principles of Active Teaching of Students." MGU, 1980.

78056578. "Theoretical and Applied Problems of Psychology of How People Get to Know One Another." Scientific Research Institute of General and Pedagogic Psychology, 1980.

78056592. "Studies of Main Parameters of Interpersonal Relations in Groups and Collectives." Scientific Research Institute of General and Pedagogic Psychology, 1980.

78056585. "Psychological Patterns of Personality Formation as Related to Home and School Rearing." Scientific Research Institute of General and Pedagogic Psychology, 1980.

78056590. "Studies of Mechanisms of Scaling and Physiological Correlates of Subjective Psychological Scales." Scientific Research Institute of General and Pedagogic Psychology, 1980.

78056583. "Differential Psychological Patterns of Formation of Occupational Fitness." Scientific Research Institute of General and Pedagogic Psychology, 1980.

78056588. "Psychological Patterns of Development of Motivation of Activity of School Children as a Condition for Upbringing." Scientific Research Institute of General and Pedagogic Psychology, 1980.

78056580. "Education and Development of Personality." Scientific Research Institute of General and Pedagogic Psychology, 1980.

78056602. "Psychological Patterns of Polytechnical Vocational Training." Scientific Research Institute of General and Pedagogic Psychology, 1980.

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PSYCHOLOGY AND ROBOT TECHNOLOGY

Moscow PSIKHOLOGICHESKIY ZHURNAL in Russian No 3, 1980 pp 123-133

[Article by Ye. P. Popov]

[Text] The use of automatically operating robots in many sectors of industry [10, 11] and other areas of human endeavor [7, 12] has great scientific-technological, economic and social significance. Use of robots in industry is altering radically the nature of labor [5, 6]. Man is being relieved by robots from the performance of monotonous, heavy, tiring and dangerous manual operations. Industrial traumatism is dropping and labor safety is increasing. With the use of robots there is substantial improvement of general sophistication of production, which aids in overcoming the differences between physical and mental labor, i.e., achieving social homogeneity of a socialist society. Thanks to the use of robots in different sectors of the national economy, only the forms of physical labor that are directly involved with intellectual activity, creativity and the skillful actions of human hands will be left to man. Beneficial conditions are also being created for the comprehensive and harmonious development of man's personality. In order to have labor become a psychological need of man, the work process proper must be intellectually saturated, with elimination of monotony and sameness.

The use of technological robot systems makes it possible to advance to new, more progressive forms of organization of labor: the technological process is changing, the quality and homogeneity of production are improving, the undesirable consequences of fatigue and accidental inattention of the worker are ruled out, not to mention the increased labor productivity and simplicity of scheduling two- and three-shift operation of equipment. Use of robots that can be easily readjusted for different operations will reduce drastically the time required for industry to take on a new production and it will reduce substantially obsolescence of equipment.

Robots and technological robot systems are a powerful means of modern scientific and technological progress. They are the offspring of the scientific and technological revolution.

It must be stated that producers did not immediately comprehend the enormous significance of robot technology. There was a sort of psychological barrier, distrust of the capabilities of robots. The old conceptions of a robot as a likeness of man (even in appearance), which were inspired by science-fiction held firm. However, the very first practical use of industrial robots, which had basically new capabilities with respect to ridding man of routine physical labor, soon caused a psychological change in the consciousness of producers.

At present, requests for industrial robots have started to exceed by many times the planning and production thereof, although there was substantial overfulfillment of the plan for robot production under the current 5-year plan. In the last few years there has been a drastic breakthrough in robot technology. And, while very recently the word "robot" was not used at all in official documents, it now appears in state programs as an important means of improving the efficiency of production, especially in view of the adverse demographic forecasts.

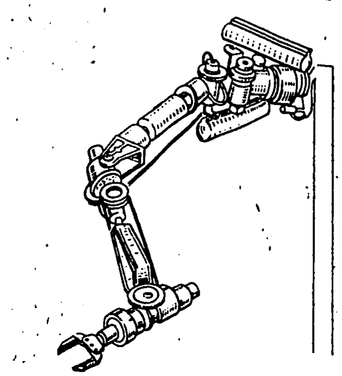

Figure 1.
Manipulator of anthropomorphic design

The foregoing indicates that, in view of the started and future wide use of industrial robots, and in view of the important social consequences thereof, it is imperative to conduct comprehensive psychological studies in this field [1-4].

The types of manipulating robots and robot-technological systems that exist now and will be developed in the future can be divided into two major classes: 1) automatically operating robots, which includes most modern industrial robots; 2) remote-control manipulating robots controlled by an operator, chiefly for use under extreme conditions, where human vital functions are either impossible or hazardous. Moreover, there are other classes of robots, but we shall discuss here only manipulating ones, i.e., those equipped with manipulators as working organs. The division of robots into the two above-mentioned classes is quite essential from the standpoint of the link between robot technology and psychological science.

The manipulating robots that work automatically consists of a multi-element manipulator and automatic control system, which consists of various measuring sensors, data processing devices, controls and drives. The elements of the manipulator are connected to one another with either rotating hinges or forward-moving guides (telescopic). In the former case, one says that the manipulator has an anthropomorphic kinematic design, since all of its elements are merely displaced by rotation in relation to one another, similarly to a human hand (Figure 1). Most often, the manipulators of modern robots make use of nonathropomorphic systems, in which some of the connections of elements are hinges and some telescopic, i.e., some units may move forward, lengthening or shortening the "arm" of the robot (Figure 2). One end of the manipulator is attached to the housing of the robot (shoulder joint) while a grip or some tool is placed in the other end (wrist joint).

The reciprocal movement of elements of the manipulator are made by means of controlled drives (electrical, hydraulic or pneumatic). The automatic control system must allow the coordinated movement of drives in all articulations, so that the end point of the manipulator would be purposefully displaced in the work space, while the grip or tool would have a specific angular orientation to perform the work operation. There must be three degrees of freedom of manipulator movement to reach any point of the work space. Three more degrees of freedom are needed to give the grip any angular orientation at this point. Consequently, the elements of the manipulator must have six degrees of mobility, i.e., it should have six elements with cylindrical hinges or telescopic devices.

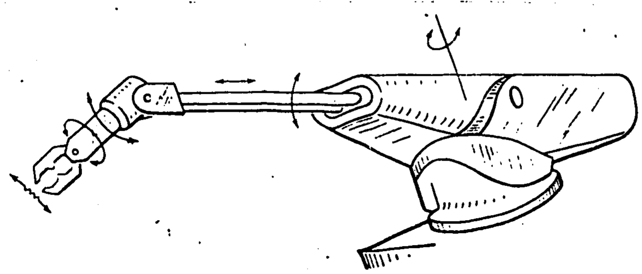

Figure 2. Manipulator of nonanthropomorphic design

The manipulator with six degrees of movement is universal. Like the human hand, it can perform any manipulative operations within a specific work space. However, in many cases, there is no need for such universal action, and there are robots with fewer degrees of mobility (3-5). In other cases, on the contrary, more degrees of mobility (7-9) are required. This surplus is needed in a universal manipulator when one must reach any point in space and the required orientation of the grip with different configurations of relative position of elements, for example, when there are various obstacles in the work space that the robot's "hand" must bypass in different ways.

A distinction is made between three types of automatic control systems for robots: 1) programmed, b) adaptive and c) "intellectual" (integral).

This corresponds to three "generations" of robots (Figure 3). The transition from one type of automatic system to another follows the hierarchic principle [7, 8]. In the first case (a), the control system operates in accordance with a rigid program which, however, can be readily readjusted for any set of manipulative technological operation. But after each adjustment, the robot repeates the rigidly programmed operations many times. All these programs can be executed either in a computer included in the robot control system or a special program device. In this case, the robot control system has two hierarchic levels: executing (control drives of the manipulator) and controlling (Figure 4). The task for the latter includes formation and distribution of control signals over all drives so that the tip of the manipulator (with grip or tool) would obtain the movement required by the program.

An adaptive system, which is the second type of automatic control system (second "generation" of robots), has two controlling levels over the former executing one, which are called tactical and strategic (Figure 5). The role of the last of these consists of "adaptation" to the actual situation in the work space and choice of suitable programs from the set of programs in the controlling computer for various elementary operations, from which the technological operation as a whole, as required by the situation, is formed. Thus, on the strategic level, there is flexible programming of operations in the adaptive system, which adjusts to the situation in the work space. Then the underlying tactical level effects, as in the preceding system, formation and distribution of control signals over all of the drives of the manipulator to execute the program specified from the strategic level.

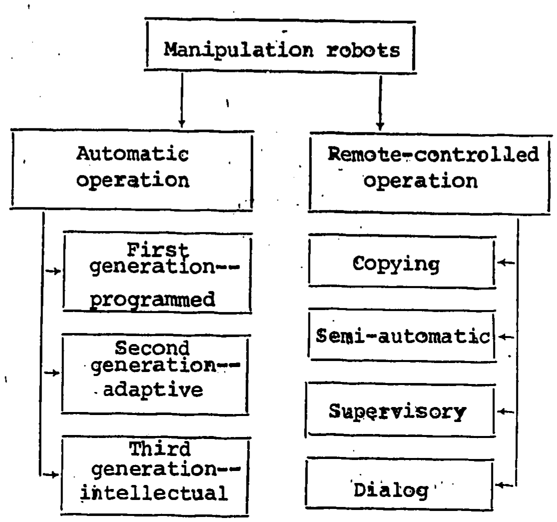

Figure 3. Classification of manipulating robots

In addition to the two above-mentioned controlling levels there are also sensory devices in the adaptive system, which consist of sensors (tactile, ranging and others) that are installed on the manipulator grip, and a system of processing information from these sensors for input in the strategic level of control, which becomes able to adapt to the situation thanks to such a sensory system.

On each controlling level and in the senosry system there may be their own built-in computers, which will be quite compact in their microprocessor execution.

The third type of automatic control system (third "generation" of robots), the "intellectual" or, as it is also called, integral system, is characterized by addition of one controlling level that is called the highest (Figure 5), which contains elements of "artificial intelligence." This includes technical devices (containing computers) which, on the basis of the well-developed system of sensing and artificial vision, automatically identify the situation in the work area, construct a simplified model of the environment in the computer, automatically produce a decision as to future actions of manipulators in accordance with the technological operation generally specified by the goal. Here we may also be dealing with self-learning of the robot from the work experience accumulated in its memory. Then the elaborated decision is transmitted "down" to the strategic level and the entire subsequent chain of levels, as in the preceding system.

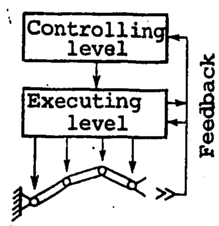

Figure 4.
Structure of programmed robot

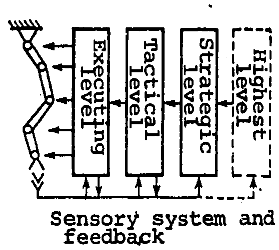

Figure 5.
Structure of adaptive and "intellectual" robots

It must be stated that the terms ascribed to a technological robot system, which correspond to names of human properties, cannot be taken literally: they merely reflect functional analogy of the end result, but by no means the essence of processes, let alone the physical nature. However, equipment based on bionic principles, including simulation of some psychophysiological properties of man, would also be useful.

At the present time, virtually all industrial robots are still first generation manipulating robots. Large numbers thereof are in use in industrial shops. The robots of the next two generations are essentially at the stage of theoretical and experimental development, although the most elementary adaptive robots are already appearing and being used in idnustry.

Why are adaptive and "intellectual" robots needed? Are not universal programmed robots sufficient? The fact of the matter is that programmed robots are adjusted each time to perform rigidly programmed manipulations, perhaps even complicated ones. This means that the situation in the work space must also be determined; all of the objects, with which such a robot manipulates, are situated in strictly specific places and oriented in a certain way. This is the case in many production shops, but not always by far. If, for example, an object is placed at random, or a choice must be made between two different objects, already one needs an adaptive control system, which would adapt, at least in an elementary way, to a situation that is not entirely certain. This does not present any difficulty for man, while performance of an automatic adaptive process in a robot is not simple in all cases. Production conditions require that such problems be solved, in each instance, with the simplest and most economical equipment, and this requires serious research and inventiveness.

This problem is also complicated by the fact that the situation is not certain, not anticipated in advance, and it changes, since the nature of manipulative operations is determined by this situation; this is when it is necessary to develop automatic control systems with elements of artificial intelligence.

An even broader range of interests of psychological science is related to remote-controlled manipulating robots, since in this case a human operator is directly involved in the control process, combined with diverse automatic equipment, computers and a complex, mechanically controlled object (Figure 6) [8, 9].

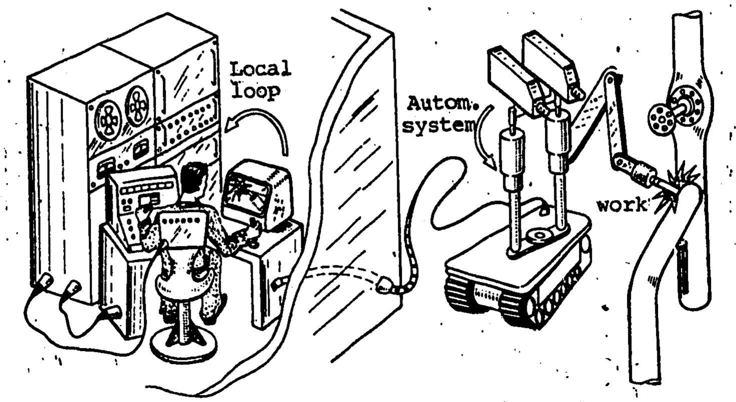

Figure 6. Remote-controlled interactive system of observation and control

It is often necessary to use remote-controlled manipulating robots in so-called extreme conditions, when man cannot work for a long time and efficiently, even with protection (in the presence of radiation, gas contamination, danger of explosion, high and low temperatures, powerful magnetic fields, under water, in open space). The fact of the matter is that, under such extreme conditions, when man is not present in the work zone, it is often necessary to perform some rather complex manual operations. However, the present level of development of robot technology does not provide for this yet. Then, in addition to a local automatic control system, a remote observation and control loop [circuit] is used, so that an operator situated at some safe distance from the work place can continuously monitor the actions of the robot and the situation around him, and he can intervene when necessary in the process of controlling it. Thus, in cases that are complicated [difficult] for the robot, natural human intelligence is added to the system to identify the situation and make decisions concerning the needed purposeful actions of the robot. As a result, one obtains an interactive system for control of the manipulating robot, i.e., a system involving active interaction between man and machine. Here, we should consider two interrelated processes, which determine the actions of an operator in a technological robot system: observation and control. For this purpose, the operator's console is equipped with screens and monitoring instruments, as well as some equipment for control. In view of the universality of the robot's manipulating system, its multipurpose design and readjustment for any sets of mechanical "manual" operations, apparently it is necessary to make use of the entire armamentarium of engineering psychological, ergonomic ideas and methods to develop and operate such systems.

The operator can conduct the observation process by means of television and other optical equipment, acoustic and other diverse devices, depending on the properties of the environment and objects of action in the distant work zone of the robot. The operator must have a three-dimensional idea about the entire work space and movements of the robot's manipulators. The requirements of effectiveness of the process of operator observation of actions of the robot and his environment are closely linked with the mental and physiological properties of man. There must be optimum selection of observation equipment and means of visualization of information from the standpoint of graphic perception, minimal fatigue of man, possibility of calm and confident identification by him of the situation in the remote work zone of robot action.

Diverse methods can be used for control by the operator: 1) copying; 2) semiautomatic; 3) supervisory; 4) dialog (Figure 3), with many variants of each of these methods.

The copying method consists of having the operator use his hand to control the setting mechanism on the console that is kinematically similar to the actuating manipulator of the robot. Each hinge of the setting mechanism is connected by a separate remote tracking system to the corresponding manipulator hinge (Figure 7). Tracking system setters are installed in the setting mechanism and actuating drives in the robot manipulator. There are communication lines between them. As a result, all of the units of the robot's manipulator repeat precisely all movements that are made by man on the remote setting mechanism.

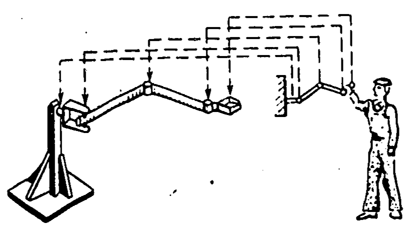

Figure 7.
Principle of copying control

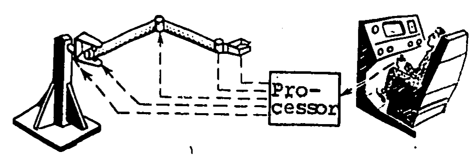

Figure 8.
Principle of semiautomatic control

In developing the copying method of control, tracking systems with two-way action are produced in order to enhance the efficiency of operator work, i.e., reflection on the operator's hand of the exertion (perhaps on a reduced scale) that actually takes place with operation of the manipulator. This approximates man's actions to the customary conditions when he does use his hands and makes use of two channels of observation, visual and tactile, sensing the direct work effort. In such a system of two-way action, there are both setters and drives (to create exertions) on both ends of the tracking systems, in all hinges of the setting mechanism and manipulator. There are different variants of two-way action systems, in which the exertions are not constantly reflected on the human hand, but only in the intervals when this is indeed necessary (so as not to tire man with a force load) in the course of the process. Specific psychophysiological studies are needed to find the optimum solution to these problems.

The next control method, which is semiautomatic, differs in that the control mechanism has the form of a multistep handle with small displacements for each degree of freedom. The electrical signal taken from it is fed to a processor [calculator], which forms control signals for all drives of the manipulator, so that the end point would acquire the necessary movement (Figure 8). Here, unlike the copying method, the kinematics of the control handle are unrelated to the kinematics of the manipulator, and can be selected separately, on the basis of convenience of actions by the operator, whereas the kinematic system of the manipulator is designed in the interests of optimum manipulation in the work zone. A minor depression of the handle by the operator elicits a signal, according to which either the speed mode is set, through the processor and communication line, when a certain vector of velocity is generated at the end of the manipulator (for transporting movements), or a positional mode, with the required magnitude of displacement of the extremity (for small movements around the object of work), or a force mode, with the required vector of manipulator action force (when it comes in contact with the object).

Each of these three variants of semiautomatic control requires its own algorithms of formation of control signals in the processor. For this reason, one has to switch the processor to various algorithms in the course of controlling movement of the manipulator, since no significant accuracy over the coordinates is required for a transporting movement of the grip or tool from one place to another. For this reason, one uses the simplest mode here, the velocity mode. But when the grip or tool is in the vicinity of the object of robot action, the tip of the manipulator must move with adherence to rather precise spatial position (according to linear and angular coordinates). Consequently, the positional mode is used for this. Finally, the force mode is set when there is direct contact between the grip or tool and object, when it is necessary to maintain a specific magnitude and direction of force.

In the first two modes (velocity and positional), the processor forms the velocity vector or, respectively, displacement of the tip of the manipulator proportionately to movement of the control handle in magnitude and direction when the operator depresses it with his hand. In the third mode (force), the processor forms the force vector on the tip of the manipulator, similar to the force vector of the operator's depression of the control handle. There may also be systems that combine only velocity and positional modes, or even one of them. Reflection of the working force from the manipulator to the person's hand (force sensitization of control handle) can be effected by different means, including vibrotactile.

The advantages of the above-described semiautomatic control method over the copying method consist, in the first place, of the fact that only slight depression of the control handle with small displacements is performed and, in the second place, that the kinematic system of the control handle can be designed on the basis of ergonomic requirements, regardless of the system of the manipulator. However, one must be concerned here with minimal intellectual and psychological load on man, which could occur if a poor choice of kinematic systems is made.

Both of the described methods (copying and semiautomatic) or, more precisely either one, are used by the operator at the time when an automatically functioning robot finds itself in a difficult situation, and the operator who is constantly monitoring its actions is compelled to take over further control of the operation.

The next method of remote control, supervisory, implies that the "robot""knows how" to automatically perform all elements of the set operation individually. However, it has to be switched from one part of the operation to another in the order required to perform the set task. Then the operator, observing the actions of the robot and the situation, and knowing what the set task is, forms a plan of action and gives the robot goal-directing orders, through which first one, then another program is turned on for the automatic operation of the robot (Figure 6). The goal directions can be made by man by different means: pencil light on a screen, depressing a key and others. The automatic actions of the robot to execute each order can be performed either in accordance with a rigid program, or a flexible one, with adaptation to the situation (adaptive programs with the use of sensitization, self-guidance, etc.).

The dialog method is the highest form of interactive control (with activity on the part of a digital computer), and it consists of having the robot participate not only in executing orders (at least with some adaptation), but also prompt the operator as to the consequence of some step of the work (by means of specific rapid calculations and logic operations in the robot's computer), and help in identifying the situation, if this involves information processing, planning actions, etc. The final decision is made by man, and further operation is the same as with supervisory control (Figure 6). The man-robot dialog can be conducted by different means, including the use of man's natural language (written or oral). When using the dialog method of remote control, the robot itself must be either adaptive or "intellectual."

In all of the above-described variants, a remote-controlled manipulating robot is a man-machine system, in which some operations are performed by the robot independently (automatic modes of control) and some under the remote control of the operator. Which of the above-mentioned four remote control methods should be chosen in each area of application of robots is not only a technical-economical, but engineering psychological problem. The same range of problems includes the question of wise degree of automation of robot actions in the presence of a human operator, and the purposeful separation of functions between man and the controlling computer in different situations.

A remote controlled manipulating robot may be viewed as a system, in which a remote loop [circuit] for observation and control is added to an automatically operating robot (any of the three "generations"), which connects this robot to the operator's console (in any of the four variants described). However, this connection cannot be considered arbitrary. The presence of a human operator with his unique ability to perceive situations and make decisions inevitably leaves an imprint on organization of the automatic modes of the "independent" part of robot actions. While one must proceed toward more complicated hierarchic control system and sensitization for the performance of the required complex operations in completely automatic robots, in man-machine systems the question of purposeful degree of automation of robot actions is put quite differently expressly because of the presence of man. There are the conditions here to avoid excessive complication of machines, within a reasonable range, increasing the reliability and economy of the automatic part of the system. But one must not overload the operator, and achieve utmost alleviation of his work with maximum efficiency thereof.

Evidently, one must encounter here many complex set of questions from the standpoint of psychological science, the need to wisely meet many contradictory requirements. Virtually no experience has been gained in this area. There must be proper formulation of the tasks that are on the borderline between engineering sciences and psychophysiology, with the use of a complex systems approach. Not only theoretical, but numerous experimental studies are needed, dealing both with special issues and the entire complex of remote controlled technological robot systems. For this purpose, we need to develop analog-computer seminatural simulating laboratory complexes differing in scale and in diverse variants.

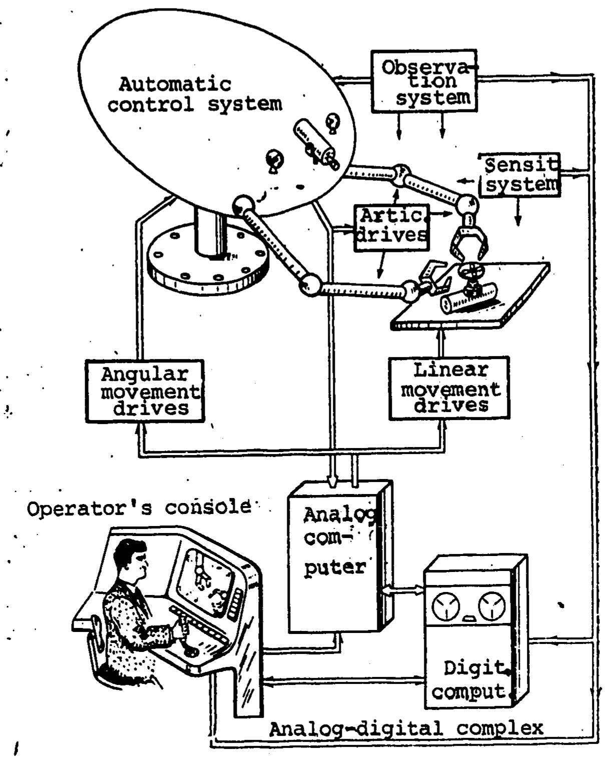

Figure 9. Structure of analog-digital seminatural modeling complex

The fact of the matter is that, in addition to work on many general problems that are referable to any man-machine technological robot systems, special studies of various areas of application of such systems are needed. For example, the purposeful distribution of functions between man and machine, and means of interaction between man and robot will differ in the following systems: remote controlled submarine technological robot systems, space systems, in atomic energy and unmanned work in mines. There will also be some specific differences between, for example, submarine robots, depending on whether they operate in the shelf zone or at considerable ocean depths, as well as whether the robot is observed and controlled from a manned submarine craft with direct visibility through portholes or from a ship on the water with observation by means of television, when one has to additionally resort to ultrasonic tracking equipment if there is turbidity, etc. There are inherent specifics in different lines of communication between the robot and operator's console; similarly, in space systems, one must take into consideration that the robot is controlled from a spacecraft or the ground. Questions of designing technological robot systems with remote control are equally important to the development of simulators for training operators and joint development of the optimum variants of systems with the operator.

Let us stress, once more, that one cannot solve the numerous problems put by robot technology to psychological science either theoretically or on the basis of the already existing experimental engineering psychological material. For this reason, new series of experiments on different levels must be conducted. Efforts have already been made to conduct experimental systems analysis on the large analog-digital seminatural simulating complex under current development, where full-scale ["natural"] robot manipulators are installed, as well as mock-ups of the environment, seminatural system of information gathering and processing, functional mock-up of an operator's console with natural means of graphic display of information and control devices that the operator handles (Figure 9). Information processing and a certain volume of software for the control system are concentrated in the analog-digital complex, with consideration of all interrelations between the technical system and the operator. Such a modeling complex could be universal, in the sense of feasibility of experimentation with any variants of man-machine robot systems for the purpose of choosing the best of them for each type of problem. This complex could also serve as the basis for developing simulator systems to train robot technician-operators.

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FIFTH ALL-UNION CONFERENCE ON ENGINEERING PSYCHOLOGY

Moscow PSIKHOLOGICHESKIY ZHURNAL in Russian No 3, 1980 pp 143-148

[Article by V. G. Zazykin and Ye. S. Romanova]

[Text] The Fifth All-Union Conference on Engineering Psychology, which was organized by the Institute of Psychology, USSR Academy of Sciences, Leningrad State University, Society of USSR Psychologists and the Leningrad Department of Scientific Organization of Labor in the Instrument Making Industry, convened in Leningrad on 2-4 October 1979. A total of 407 scientists, engineers and practicing psychologists, including 32 doctors of sciences and 140 candidates of sciences (244 psychologists, 28 physiologists, 21 specialists in cybernetics, 18 physicians and 96 engineers working in industry) participated in the work of the conference. The research centers and departments of scientific societies of 39 cities in 9 Union republics of the Soviet Union were represented. A total of 133 papers were delivered in the 10 sections dealing with engineering psychology, the section of space and aviation psychology and section of ergonomics.

The first session was opened by Prof A. A. Krylov, dean of the psychology faculty of Leningrad State University and chairman of the organizing committee. He noted that conferences on engineering psychology have become an important event in the life of psychological science. This conference was called upon to sum up the work of engineering psychologists over the last 5 years, to assess the role and significance of research in engineering psychology in solving practical national economic problems at the final stage of the 10th Five-Year Plan.

Prof B. F. Lomov, director of the Institute of Psychology, USSR Academy of Sciences, scientific administrator of the conference, delivered the opening remarks. He observed that, in the presence of complexly automated industry, great demands are made of man, due to modern technology and working conditions. B. F. Lomov stressed the importance of All-Union conferences on engineering psychology, their impressiveness and high level of scientific discussion of problems of engineering psychology. The distinctive feature of this conference on engineering psychology is that, along with traditional problems of a practical nature, broad light is shed on methodological problems, various theoretical aspects of the problem of optimizing man-machine systems.

Papers were delivered at the plenary session by well-known Soviet scientist-psychologists, and they dealt with the most pressing theoretical problems of modern engineering psychology. The joint paper of B. F. Lomov, A. A. Krylov and V. A. Ganzen, which was delivered by Prof A. A. Krylov, submitted to in-depth analysis the distinctions of development of engineering psychology in the USSR, demonstrating its solid bonds with basic and applied research in other branches of psychological science. Special attention was devoted in this paper to the fact that engineering psychology as a science is emerging more and more as a direct productive force, with regard to nature of its influence; as to the problems it studies, methods it uses and distinctions of practical applications of its results, engineering psychology is not limited to the study of patterns of information-related interaction between man and machine. It was stressed in this paper that the prospects of development of engineering psychology in the USSR are determined by the development of increasingly sophisticated technology and expansion of the area of human endeavor.

G. M. Zarakovskiy (Moscow) drew an interesting analysis of development of research in different directions of engineering psychology and their contribution to the solution of general engineering psychological problems; it was demonstrated that many engineering psychological studies are not yet being assessed on the basis of their end effect.

In the paper of Yu. M. Zabrodin (Moscow), analysis was made of the principal conceptions of engineering psychology. The author observed that, at the present time, there are two polar directions of its development: the first is largely related to the mechanocentric direction; the second line of research is determined by the development of promising approaches and conceptions primarily in Soviet engineering psychology; this refers to the construction of models that imply development of the main psychological ideas (systems approach, principle of operator activity).

Yu. M. Zabrodin stressed the need for special work on analysis of the entire system of categories of engineering psychology, definition of their place in the overall hierarchy of theoretical psychological concepts. It is imperative to intensify inter- and intra-psychological directions as we move from the "ideal" to the real object and, in particular, integration of engineering and social psychological data and methods.

Then the work of the conference proceeded in different sections.

Eight papers were delivered in the first section, "Theory and Methodology of Engineering Psychology." The speakers shed light, to different degrees, on issues related to operator activity of man, engineering psychological aspects of operator performance, formation of psychological system of performance, as well as the economic effectiveness of engineering psychological decisions.

The speech of A. P. Chernishev (Moscow) dealing with "Engineering Psychological Aspects of Operator Performance" was greeted with interest. This speaker discussed in detail the psychological aspects of operator performance, principles involved in the design of man-machine systems. He stressed that the experience of engineering psychological designing is indicative of many unsolved problems. However, even now, it can be maintained that the means of solving problems of synthesis of man-machine systems have been found on the basis of the systems approach developed by the Soviet school of engineering psychology.

V. D. Shadrikov (Yaroslavl') dwelled on questions of formation of a psychological system of performance: criteria of degree of development of operativeness [dynamism] of all elements of the psychological system of performance should become the indicators of level of preparedness of a subject for specific professional activity.

The papers of B. A. Smirnov (Khar'kov) and Ye. V. Taranov (Kurgan) dealt with economic effectiveness of engineering psychological solutions and control of the sociopsychological climate of industrial teams.

G. V. Sukhodol'skiy (Leningrad) discussed operator performance as the subject of engineering psychology.

At the first section, entitled "Psychological Characteristics of Operator Performance," there was exchange of information pertaining to studies of various psychological characteristics of operator performance. Ten papers were delivered. Those of S. S. Gremyachenskiy and V. I. Shapovalov (Moscow) dealt with studies of the properties of sensory "input" of operators in detection problems, influence of various factors on efficiency of performance. Questions of optimization of processing of polymodal information were discussed in the paper of T. P. Zinchenko and O. A. Il'chenko (Leningrad), which stressed that the results of their study demonstrated that there was rather high efficiency in processing bimodal--visual and auditory--information provided the signals addressed to specific analyzers carry information that differs in content.

Problems of studying processes of operative [immediate, dynamic] thinking and decision making occupied an important place in the work of this section (the papers of D. N. Zavalishina, V. D. Magazannik--Moscow, A. I. Naftul'yev and A. N. Tolstaya--Leningrad).

In several papers, an attempt was made to shed light on the problem of improving the efficiency of operator performance (Yu. F. Isaulov and N. M. Lebedeva, V. P. Sal'nitskiy, R. V. Komotskiy, M. M. Skvortsov, I. V. Kashlyak, M. S. Kapitsa and B.M. Velichkovskiy--all from Moscow).

At the third section, "Psychophysiological Characteristics of Operator Performance," a wide spectrum of papers was delivered, which considered the psychophysiological characteristics of operators from different aspects of theoretical and experimental research. Virtually all of the speakers mentioned the need for the systems approach to analysis of mental states of man. There was reflection of knowhow in experimental and theoretical research of mental states of an operator in the speeches of L. D. Chaynova and M. V. Yermolayeva (Moscow), Ye. P. Il'in, M. A. Zamkov and Yu. A. Katygin (Leningrad).

In the paper of V. A. Ganzen and V. N. Yurchenko, there was a description of an attempt to apply systems methodology to the study of mental states of man, as a result of which three substructures of mental states were described: hierarchic, coordinating and a group of special characteristics. The attitude of man is a system-forming characteristic of the component composition of any mental state. The potential of the approach they developed was tested on such mental states as stress and fatigue.

Ye. P. Il'in, M. A. Zamkov and Yu. A. Katygin (Leningrad) concluded, on the basis of experimental studies, that the common nature of the main mechanisms of development of the state of monotony is unrelated to the type of monotonous work.

The paper of N. V. Krylova, "Distinctions of Operational Memory in the Presence of Emotional Tension," dealt with the distinctions of mnemic functions of operators in the presence of real stress--parachute jumps. The submitted results are of definite interest to the study of the effect of tension on quality of operator performance.

Several applied aspects of research on psychophysiological characteristics of operator performance were reflected in the papers of A. F. Bystritskaya and A. A. Loseva, I. B. Solov'yeva, O. V. Osipova, I. N. Volkova, Z. S. Kalashnikova, T. Ye. Sazanova, L. G. Rusakova, T. T. Rukavishnikova, S. D. Migachev, B. G. Ushakova and Ye. P. Sviridova.

Fourteen papers were delivered at the section entitled "Engineering Psychological Design of Operator Work." They reflected chiefly the different aspects of this focal task of engineering psychology, pertaining mainly to the design of external means of operator work. These were the papers of S. V. Borisov, M. R. Shagalova, V. M. Bondarovskaya, R.V. Gorovoy, D. B. Bogoyavlenskaya and M. S. Podolyak.

The papers of V. A. Vavilov, D. K. Fedotov, E. K. Rinkus, L. N. Vyshchepan and I. Z. Kovalev dealt with modeling as one of the most popular means of describing operator performance.

In a paper entitled "Construction of Course of 'Engineering Psychological Design,'" M. M. Knyazev summarized experience in teaching this discipline at the Yaroslavl' State University. The paper of G. N. Solntseva and G. L. Smolyan (Moscow) analyzed some methodological problems of designing operator work, particularly questions pertaining to the concept of designing activity.

N. M. Rudnyy, G. V. Kaliberdin and B. L. Gorelova (Moscow) submitted a set of organizational and methodological principles referable to support of designing man-machine systems, which could serve as the basis for developing the appropriate standards and specifications. V. F. Venda and Ye. P. Yermolayeva (Moscow) reported on the problem of defining the set of psychological factors of complexity and determination of the degree of their importance in solving tasks of semi-automatic control of a nuclear reactor. M. S. Ter-Mkhitarov (Perm') devoted his paper to analysis of specific methods of designing such systems. V. L. Chistyakov (Odessa) discussed maritime craft and dwelled in detail on questions related to operation thereof.

There was discussion of 11 papers at the fifth section, "Professional Screening and Guidance," most of which dealt with questions of effectiveness of the system of psychological screening. V. A. Bodrov and N. F. Luk'yanova (Moscow) delivered a paper entitled "Use of Methods of Examining the Personality for Screening and Expert Certification of Pilots," and submitted the results of using a set of personality-testing methods to study the process of adaptation to flight training. Several special scales were singled out for predicting learning achievement.

A. T. Rostunov (Minsk) stressed that it is important to disclose the true motives for choosing the operator profession in the course of professional screening, as well as the existing abilities of applicants and possibility of further development thereof.

T. A. Yemushko, S. N. Dotsenko, I. M. Kutsevich and T. M. Kuz'mina singled out criteria of professional fitness and specific methods for screening operators in different special occupations.

G. A. Norkina, R. M. Bulatova and I. M. Yusupova, O. V. Belyy, T. V. Vol'manova, B. N. Reshtuk, V. A. Alekseyenko and S. V. Artamonova discussed the influence of diverse factors on the conduct of professional psychological screening.

The studies of G. A. Yermak, V. P. Logvinenko and V. N. Chetvertak submitted the results of using the personality tests by the methods of MMPI, Rosenzweig and contrology for professional screening of skilled assembly plant workers.

The section of "Professional Training of Operators" was represented by 10 papers. Several of the delivered reports dealt with experience in using special equipment to enhance the efficacy of training (papers of M. S. Ter-Mkhitarov, I. D. Kolodnyy, V. A. Zhilin, R. S. Araslanova, V. G. Bunurova and I. K. Shirokova, Yu. G. Shterenberg, A. V. Al'bokrinov, O. A. Tarnovskaya). Probabilistic criteria and various methods of evaluating the level of operator training referable to man-machine systems were discussed in the papers of Yu. B. Bluvshteyn and N. K. Zlatorunskiy, "One Method of Evaluating Actions of Trainees Using Simulators," and by A. I. Gubinskiy and R. S. Grayfer (Leningrad), "A Method of Complex Evaluation of Learning Achievement of Operators for Computer Peripherals and Technical Execution Thereof."

The paper of V. V. Balyasnikov and G. S. Karapetyan, entitled "A Method of Quantitative Evaluation of Pilot Training on the Basis of Analysis of His Control Signal Time Lag," dealth with questions of training pilots for the civil aviation according to characteristics of time lag in pilot control actions in response to one of the stimuli delivered over the most important channel.

Problems related to development of rational methods of training operators for work involving occurrence of stress and extreme situations were discussed in the papers entitled "Training Operators to Solve Emergency Problems" by N. M. Panasenko and I. G. Tsvetkova, and "Questions of Upgrading Professional Training of Operators in Extreme Modes of Work," by L. S. Nersesyan, Ye. G. Burekhzon and D. N. Skorobogatov.

Nine papers were delivered in the section entitled "Synthesis of Systems for Display of Information." V. F. Venda, in his paper entitled "Engineering Psychology and Information Equipment," dwelled on problems of developing systems of information display at the present stage. Questions of collective nature of operator work in complex automated systems were the topic of the paper of B. S. Berezkin, V. I. Drakin and V. Ye. Lepskiy (Moscow). The papers of V. K. Dineyka, G. N. Il'ina, M. D. Gusyatnikov, I. I. Litvak, M. K. Tutushkina, K. A. Sabitov and B. N. Gerasimov dealt with applied questions related to development and design of means for displaying information.

The paper of V. A. Ganzen, L. P. Komlev, and I. A. Shikhin (Leningrad) shed light on the main principles involved in improving the effectiveness of reading texts consisting of synthesized symbols. The technical, psychological and sociopedagogic aspects of this problem were mentioned.

Eight papers were delivered in the section of "Group Operator Performance." The paper entitled "Influence of 'Leader-Follower' Structures on Efficiency of Group Performance," by V. Ye. Lepskiy, M. A. Novikov and V. F. Rubakhin (Moscow) discussed problems of distribution of functions and their influence on efficiency of group performance in problem situations. The paper of N. A. Tarasova and A. P. Chernyshev (Moscow) dealt chiefly with methodological aspects of the problem of group dynamics while tracking. The methods and evaluation criteria elaborated by these authors expand substantially the possibilities of investigation.

The papers of G. A. Navaytis, A. A. Krylov, G. S. Nikiforov (Leningrad), V. I. Bogomolov, G. V. Lozhkin, V. A. Stanovov and Ye. D. Margulis (Kiev) dealt with problems of interpersonal relations and influence of nature of interactions on efficiency of group work. Problems of modeling group work and equipment used for studies of such problems occupied an important place in the work of this section. Papers on this topic were delivered by T. A. Matalina and Ye. Ya. Semenyuk--"Homeostatic Model of Dominance," and by V. I. Kalin, V. V. Mayboroda, V. I. Donskoy and I. Yu. Zaglyadnyy--"A Stand for Testing Individual and Group Operational Thinking While Controlling Inertional Objects."

In the section entitled "Reliability of Man-Machine Systems," 12 papers were delivered. In the paper entitled "Interrelation Between Flawlessness and Speed of Operator Performance," by A. I. Gubinskiy and V. M. Popov (Leningrad), a method was proposed for vector evaluation of reliability of operator performance, with the use of aberration ellipses. The paper of Ya. I. Tsurkovskiy (L'vov), "Improvement of Work Quality and Production Reliability From the Standpoint of Theory of Mental Control," dealt with methodological problems of relation of controllability theory and reliability of system work. At this section, a group of papers was delivered, which discussed the influence of various factors on reliability of performance of operators and man-machine systems. They were authored by S. A. Ishkhanyan, R. V. Aguzumtsyan, B. M. Mirzoyev, N. A. Nosov, V. K. Safonov, V. K. Gerbachevskiy and Ye. V. Markov.

Several papers dealt with problems of labor safety and prevention of traumatism as factors in assuring reliability. These were the papers of M. V. Vakhidov and S. A. Yeliseyev (Tashkent), I. V. Dement'yev, Yu. F. Gushchin and V. N. Bezrodnyy (Donetsk).

The influence of various factors on reliability of operator performance at modern rolling [milling] plants were discussed in the papers, "Study of Preparedness of ASUTP [Automated System for Control of Technological Processes] Operators for Active Actions," by V. K. Kashin (Leningrad), and "Communicative and Personality Aspects of Reliability of Operator Work," by Ye. S. Rybalko, R. A. Maksimova and R. A. Volkova (Leningrad).

The section of "Verbal Communication" was represented by six papers. The paper entitled "The Role of Verbal Operator Activity Under Extreme Conditions," by S. A. Kiselev, G. M. Kolesnikov, N. V. Krylova and I. B. Solov'yeva (Moscow) dealt with the role of verbal activity in enhancing the efficacy of processes of vocational training under extreme conditions. The paper of I. N. Lushchikhina and L. N. Solov'yeva (Leningrad) discussed problems of consideration of individual psychological traits of students in the course of professional psychological screening. In his paper, N. T. Yerchak dwelled on questions of informativeness of sounds in words and phrases in solving problems of word-by-word synthesis for verbal interaction in man-computer systems. The papers of M. V. Frolov, V. Kh. Manerov and T. A. Shatalova, and Ye. N. Grigor'yev discussed applied questions related to the problem of verbal communication. Much interest was displayed at the meeting of the section of "Space and Aviation Psychology." Six papers were delivered, and they reflected the experience of experimental and theoretical research on various problems of aviation and space psychology.

The papers of V. F. Venda, L. G. Dikaya, V. A. Popov (Moscow) and L. P. Grimak, L. G. Dikaya, O. M. Salmanina dealt with the influence of functional state on adaptation processes. The relationship between processes of human adaptation and indicators of reliability under extreme conditions was discussed by A. V. Zakharova, L. A. Kitayev-Smyk, V. A. Chursinov and V. V. Danilovtsev (Moscow). Problems of cosmonaut efficiency during long-term flights and methods of predicting it were the topics of K. K. Ioseliani and V. I. Myasnikov (Moscow). The paper of A. I. Prokof'yev and S. I. Rogachev (Leningrad) covered problems of information support for pilots in the civil aviation.

Prof A. A. Krylov, G. V. Sukhodol'skiy and other participants at the conference delivered speeches at the closing plenary session. The decision adopted by the conference outlined the routes of development of the main directions of engineering psychology and for improving the organization of training of engineering psychologists.

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